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FINAL TECHNICAL REPORT PR 80-1-307

Decision Analysis of Advanced Scout Helicopter Candidates

LEVEL II

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DECISIONS and DESIGNS, INC.

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Prepared for
The U.S. Army
Aviation Research and Development Command
Contract DAAK50-79-C-0035

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~~This report describes~~ an analysis ~~of~~ thirteen Advanced Scout Helicopter (ASH) candidates and mixtures of those candidates. The analysis evaluates the candidates on the basis of their military worth; life cycle costs; attainability; force structure personnel impact; and rationalization, standardization and interoperability impact. The major portion of the report describes and explains the methodology used to evaluate the candidates, presents the results of the analysis, and illustrates several of the sensitivity analyses that were performed. Detailed assessments used in the analysis are reported in the appendices.

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ABSTRACT

This report describes an analysis of thirteen Advanced Scout Helicopter (ASH) candidates and mixtures of those candidates.

The analysis evaluates the candidates on the basis of their military worth; life cycle costs; attainability; force structure personnel impact; and rationalization, standardization, and interoperability impact. These major evaluation categories are subdivided in such a way that over seventy attributes of value are considered.

The analysis identifies as the best ASH candidate the new development with a single advanced technology engine. In addition, three candidates and one mixture of candidates are identified as the best, according to the criteria specified above, if cost is constrained at lower levels.

The major portion of the report describes and explains the methodology used to evaluate the candidates, presents the results of the analysis, and illustrates several of the sensitivity analyses that were performed. Detailed assessments used in the analysis and extensive rationale supporting those assessments are reported in the appendices.

The report also describes an analysis aimed at improving the design of ASH candidates. Because this analysis was not developed beyond an early stage, its results should not be used to draw conclusions about any ASH design.

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1.0 INTRODUCTION

1.1 Background

The Advanced Scout Helicopter Special Study Group (ASH SSG) has been tasked by the Army with defining and demonstrating the need for an ASH, with selecting an effective and affordable ASH program, and with demonstrating that the chosen ASH alternative is more cost effective than the other alternatives considered. The ASH SSG must build support for the ASH based upon an understanding of basic operational and organizational concepts. Their studies must be requirements rather than hardware oriented. In particular, the ASH SSG must demonstrate that the ASH need cannot simply be met by the current Light Observation Helicopter (LOH) being used for the ASH role.

1.2 Objectives

Given the above described need, Decisions and Designs, Inc. (DDI) set out to assist the ASH SSG by constructing a comprehensive ASH evaluation model utilizing multi-attribute utility assessment (MAUA) modeling. MAUA is a form of decision-analytic modeling that allows the incorporation of all objective as well as subjective data that might influence the choice of one ASH candidate over another. Both hardware and operational characteristics of the candidates are incorporated in this single model. Simulation data and results are included as well. The output of the MAUA model is a numerical representation of the worth of each ASH candidate. These numbers are highly supportable via carefully recorded written rationale and, together with the relevant cost data, can be used to calculate the cost effectiveness of each ASH candidate. In the remainder of this report, the nature of the entire modeling effort for the ASH SSG is thoroughly detailed.

1.3 Descriptions of ASH Candidates

The main portion of this project involved an evaluation of thirteen candidate Advanced Scout Helicopter (ASH) designs and mixes of these designs. These candidates are listed, together with three-character identifiers, in Table 1-1. Detailed descriptions of the candidates are given in the "Special ASH Issue" of Army Aviation[1] and will not be repeated here. We will, however, point out some of the major characteristics of the candidates in paragraphs below.

The first four candidates listed are completely new developments. These candidates are the result of design studies that started from scratch with a "clean sheet of paper," unconstrained by current helicopter designs. All of these designs incorporate a full complement of mission equipment; they differ mainly in the number and power of engines--although all designs incorporate an Advanced Technology Engine (ATE)--and in the seating arrangement for the crew. BTA is a single-engine helicopter that configures the crew in a side-by-side seating arrangement. BT2 has twin engines and a side-by-side configuration. BTT has twin engines and a tandem configuration (with a frag barrier that provides the crew with protection against a 23 millimeter high explosive round). B4K has twin engines and a tandem configuration; it also has the capability to operate under 4,000 feet/95° F conditions with one engine inoperative.

The next six candidates are modifications of existing attack helicopters. The first three candidates are variations of the OH-58C. The OH-58D is a minimal modification

[1] Volume 28, Number 10, 1 October 1979.

New Developments

BTA:	New Dev 1 x ATE	
BT2:	New Dev 2 x ATE,	SXS
BTT:	New Dev 2 x ATE,	Tandem
B4K:	New Dev 2 x ATE,	SXS, with 4K/95 OEI

Modifications

58C:	OH-58C
58D:	OH-58D
58E:	OH-58E
OHT:	OH-1 with TADS
OHM:	OH-1 with MMS
064:	OH-64

Others

350:	Aerospatiale AS 350
129:	Agusta A129
500:	Hughes 500D

Table 1-1

THE THIRTEEN ASH CANDIDATES

that involves principally the addition of a mast-mounted sight (MMS), with day-only capability, and some extra mission equipment (the OH-58D does not meet the specified ASH maneuverability requirement). The OH-58E is a more substantial modification that includes a four-bladed rotor, a MMS equipped with day-television and forward-looking infrared (FLIR)--for night operations--and an upgraded transmission and engine. The next two candidates are modifications of the AH-1 attack helicopter. OHT is the minimal modification that fits the AH-1 airframe with a nose-mounted target acquisition and designation system (TADS). OHM is a more substantial modification that fits the AH-1 airframe with a four-bladed rotor and the full complement of ASH mission equipment with a modular MMS. The OH-64 is a modification of the YAH-64 attack helicopter that leaves the weapons systems intact but removes the weapons.

The final three candidates are derivatives of helicopters that are currently in existence or under development. These include the Aerospatial AS-350 (350), the Agusta A-129 (129), and the Hughes 500D (500).

2.0 THE EVALUATION MODEL

This chapter describes the results of an effort to capture in a single comprehensive model the many factors that could lead the Army to prefer one ASH candidate over another. Thus, it represents a substantial extension beyond the scope of those studies which deal only with cost, or only with operational effectiveness. The purpose of a comprehensive model such as the one presented here is to provide a single yardstick to compare systems by trading off one criterion against another according to their relative importance.

2.1 General Description of the Methodology

2.1.1 Overview - The evaluation model is an instance of a methodology called Multi-Attribute Utility Analysis (MAUA). In general, MAUA is characterized by the representation of outcomes in terms of a number of different criteria, rather than a single global measure of value. Various forms of MAUA are possible, differing in terms of the specific method of representing an option's score on each criterion, the structure of the relations that are assumed to hold among the criteria, and the method of aggregating the component ratings into a single overall evaluation for each option.

The evaluation model can be characterized as a relative, hierarchical, or weighted additive utility model. Each of these three concepts is explained below.

2.1.1.1 Relative scoring - In a relative model, scores on each of the attributes represent not the proportional values of the various options, but rather the relative differences among the options. The distinction between relative and absolute scoring is critical to a proper interpretation of MAUA results, so amplification is in order: An "absolute" scoring system necessitates defining a true zero level of performance and scoring systems proportional to how far they exceed that zero level; a "relative" scoring system arbitrarily selects the least desirable outcome on each criterion as a relative zero, and then scores each of the other systems proportional to the magnitude of the difference between that system and the one with the lowest score.

As illustrated in Section 2.1.2, either type of scale may be used to evaluate options. It turns out, however, that very often the "true zero" on many important attributes is so much worse than the options actually being considered that it is difficult to define or to think of. Worse still, there is often no obvious notion of a zero level of importance with any meaning to the decision makers. Finally, even if these problems do not arise, the numerical ratios may be so close as to appear indistinguishable, even when the magnitudes of the differences are quite large. For the above reasons, it is often preferable to use relative scoring, which restricts its domain of attention to the actual range of variation among the options.

The benefits of relative scoring are that it spreads the numerical scores out for better discrimination among the options, that it involves considering only the realistic options being evaluated (rather than hypothetical constructs suc' as the absolute zero), and that it requires as few elicited values as possible to arrive at a meaningful set of scores. Disadvantages include an inability to determine whether a given system is "bad" or "good" (only "better" or "worse" are meaningful), the need for caution in interpreting the numerical scores, and the impossibility of determining whether the "best" system is really significantly better than any of the others. Overall, if the goal is to select the best system, the advantages of relative scoring outweigh its problems (so long as proper caution is exercised in interpreting numerical results).

2.1.1.2 Hierarchical utility structure - It would be possible to list the entire set of attributes that might affect the preference for one alternative over another; but such a method would be highly cumbersome, difficult to communicate, and susceptible to a number of methodological biases that result from the overload of processing large amounts of information without subdividing it into manageable "chunks." One solution, which is adopted here and used in a variety of similar analyses, is to develop a hierarchical structure which expresses the overall value as the aggregate of a small number of major attributes; each of these major attributes may itself be subdivided ("decomposed") into minor attributes, which may themselves be decomposed, et cetera.

A hierarchical utility structure may be represented as a schematic tree in which the overall value appears at the top level; each of the major attributes appears as a branch beneath that top level; and component sub-attributes of a major attribute appear as branches beneath it. Thus, by referring to any label on the tree, one can simultaneously indicate not only the specific attribute named, but everything which appears beneath it (connected by branches) as well. (The hierarchical branching structure of the ASH decision model is displayed in Section 2.2.1.)

The process of hierarchical decomposition provides three important benefits: first, it breaks the elicitation process up into "chunks" of manageable size; second, it organizes the presentation of final results, highlighting the most important factors without losing the ability to retrieve details when desired; and third, it limits the required assessments to comparisons among attributes that are closely related in meaning, and therefore relatively easy to weigh against one another.

2.1.1.3 Weighted additive utility aggregation - When a given utility attribute (including the "overall value") has been subdivided into components, various rules may be used to combine the component scores into a single summary score. Most well-structured hierarchical utility models are best treated by a weighted additive aggregation rule: the summary score on a higher-level attribute is equal to the sum (or, more properly, the average) of the component scores, each weighted according to its assessed impact on the final value. These weights are, roughly speaking, a combination of relevance, importance, and variation among the options with respect to each attribute; weights are arbitrarily re-scaled in proportion to one another so that the adjusted or "normalized" values add to one (or to 100%).

For example, if the weights of three attributes are .40, .25, and .35, and if a given option's scores on those attributes are 80, 100, and 40, respectively, the overall score for that option will be (80 x .40) + (100 x .25) + (40 x .35) = 71. In order to interpret the value thus obtained, assuming a relative scoring system, the user must consider two (probably hypothetical) options: one which would combine all the most desirable features of the various options, resulting in a score of 100 on every attribute (and therefore in an overall score of 100); and another which would combine all the worst aspects of the various options, resulting in a (relative) score of zero throughout. In a relative model, a score of 71 would mean that the given option was much closer to the 100-point "best" than to the 0-point "baseline" option. (Again, the user must avoid making unjustified claims about the absolute value of an option, or about the ratio of the scores of two options; the only valid conclusions involve the rank order of preference among the options and the relative magnitudes of the differences when compared with one another.)

One difficulty inherent in relative modeling is the definition and interpretation of the weights assigned to various attributes. In any additive model, the ultimate criterion for interpreting and defining weights is the following: if an increase of p points on Attribute X is valued exactly as highly as an increase of q points on Attribute Y, everything else remaining equal, then the two attributes should be assigned weights in the proportion q:p (i.e., the more points needed on Attribute X to match the effect of the other attribute, the less weight Attribute X deserves).

Again, because of the pitfalls in interpreting relative scores, caution must be taken not to identify the weight on a given attribute as the "importance" of that attribute; a critically important attribute on which the options are all identical will properly receive a weight of zero. On the other hand, if the performances of the options on all of the most important attributes are very close, a seemingly low-priority item on which there is substantial variation may in fact receive the largest weight.

2.1.1.4 Summary of modeling procedure - The entire procedure of MAUA, as used in the evaluation model, can be divided into the following sequence of steps:

Step 1 - define the options to be evaluated;

Step 2 - define the attributes which will contribute to overall utility, and the hierarchical structure by which they are organized;

Step 3 - score each of the "data-level" attributes (i.e., those which are not further subdivided) by assigning numerical values to each option on a 0-to-100-point relative scale;

Step 4 - for every attribute which is subdivided into components, assess the weights of its sub-attributes;

Step 5 - starting with the "data-level" attributes and progressing up the tree, calculate the summary score of each option as a weighted sum of its component scores on the sub-attributes, so that the summary scores at the "overall" level represent the evaluations of the options.

Having completed these steps, the analysis team proceeds to explicate the results, perform sensitivity analysis, and otherwise facilitate the communication of the study's implications. Generally, most of the effort in a good analysis is spent in these latter activities.

2.1.2 A comparison of three methods of scaling - In the process of structuring the ASH evaluation model, a question arose over the best method of scaling to use. In particular, some concern was expressed that the relative scales, which measure the value of the ASH candidates on the 0-to-100 scale explained above, unjustly penalize the worst candidates of the group. An argument was made that the use of an absolute scale or a ratio scale might avoid this problem and thus might be a better approach. The following discussion highlights the similarities and differences among these three methods of evaluation and illustrates how all methods yield equivalent results when each is done properly.

The three methods of scaling value will be illustrated by using the following example. Suppose that a decision maker is interested in choosing the best helicopter from among the following set of three:

(a) a hypothetical new development;

(b) a hypothetical modification of an existing helicopter;

(c) a hypothetical existing helicopter.

Suppose further that the decision maker wishes to make this choice based on three criteria: procurement cost, military effectiveness, and reliability.

2.1.2.1 <u>The absolute scale</u> - The first step in an evaluation is to determine a score for each alternative on each criterion. This procedure is relatively simple for procurement cost. The decision maker specifies his utility for money over a relevant range and estimates the cost for each alternative. There is, however, already a problem with an absolute scale; the relevant range must be defined. To be truly absolute, the scale might have to extend at least from a cost of zero to a very large number that might approach positive infinity. To be useful, though, the decision maker must define some smaller range that encompasses the entire range over which he can differentiate a value for reducing cost. Assume that the decision maker defines this "absolute" range as $0 to $5 million per helicopter and that his preference is linear with cost. We can then, without loss of generality, scale the decision maker's preference for cost to be in the interval 0 to 100 using the function:

U(C) = 100 ($5 million - C), where C is cost in dollars.

Suppose that the following are the estimated costs for the alternatives, which can be converted into preference for cost by using the above transformation:

Helicopter	Cost	Absolute Score for Cost
A	$4.5 million	10
B	$4 million	20
C	$2 million	60

Next, consider the criterion of military effectiveness. For this criterion, the decision maker has another problem: to establish operational definitions of "perfect" and "unacceptable" military effectiveness--in absolute terms--or to use a more measurable quantity as a surrogate. For our example, assume that the decision maker uses Specific Exchange Ratio (SER), as estimated in a simulation, as a surrogate for military effectiveness. Again, assume that preference is linear, and further assume that the decision maker judges an SER of 0 to be totally unacceptable and one of 40 to be perfect. The alternatives might then be scored as follows:

Helicopter	SER	Absolute Score
A	30	75
B	25	60
C	15	37.5

Now, consider the third criterion, reliability. Assume that the decision maker uses Maintenance Man-Hours per Flight Hour (MMH/FH) as a surrogate for reliability; a value of 0 MMH/FH is considered perfect, a value of 5 MMH/FH is considered acceptable, and preference is linear between these extremes. The alternatives might then be scored as follows:

Helicopter	MMH/FH	Absolute Score
A	3	40
B	4	20
C	2	60

The relationships between the absolute criteria and their corresponding utility functions are shown in Figure 2-1.

2.1.2.2 The ratio scale - The decision maker could avoid the problem of defining a perfect capability, in the absolute sense, by identifying the best alternative on each criterion and measuring the performance of the other alternatives as a ratio to the best one. Consider, for instance, the criterion of military effectiveness. Here, helicopter A is best, helicopter C is half as good as A, and helicopter B is 80% as good as A. So, scores on a ratio scale would be as follows:

Helicopter	SER	Ratio Score
A	30	100
B	25	80
C	15	50

Similar transformations are possible with the other scales as well, but with the other scales the decision maker must be careful with this transformation. In particular, for a ratio scale to be compatible with the absolute scale, the "unacceptable" point of zero value must remain the same. Consider the criterion of procurement cost. Here, helicopter A is best relative to the unacceptable cost of \$5 million per unit, helicopter B is one-third as good as C relative to the unacceptable cost $\frac{\$5M-\$4M}{\$5M-\$2M} = 1/3$,

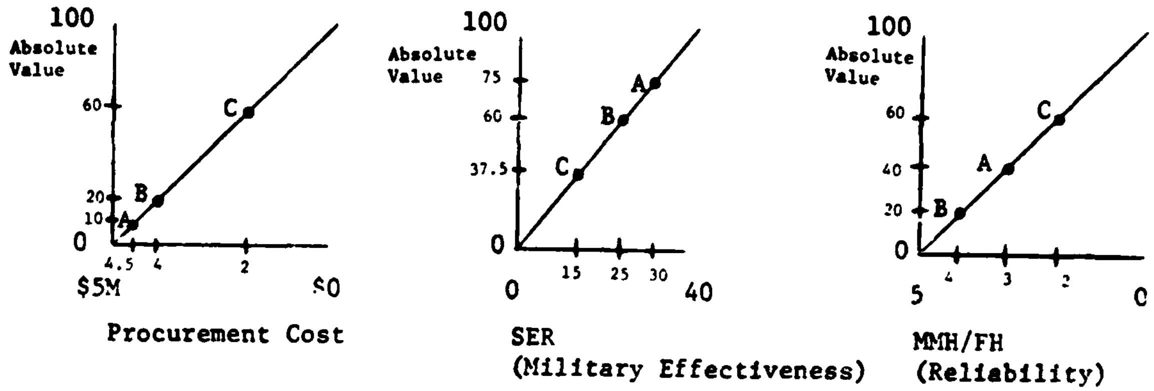


Figure 2-1

ABSOLUTE VALUE SCALES

and helicopter A is one-sixth as good as C. These observations lead to the following ratio scale for cost:

Helicopter	Cost	Ratio Score (assuming \$5 million is unacceptable)
A	\$4.5 million	16.7
B	\$4.0 million	33.3
C	\$2.0 million	100.0

Using a similar argument gives the following ratio scale for reliability (relative to an unacceptable level of 5 MMH/FH):

Helicopter	MMH/FH	Ratio Score
A	3	100.0
B	4	33.3
C	2	66.7

2.1.2.3 The relative scale - Notice from above that both the absolute and ratio scales force the decision maker to define an unacceptable level and an absolute zero on each scale. A completely relative scale, however, does not force such definitions.

Here, the scales were defined by the alternatives under consideration. With the best helicopter on the criterion defining the score of 100, the worst helicopter defining the score of 0, and the other helicopter being scored in relation to the other two, the following relative scales are defined:

Helicopter	Cost	Relative Score
A	\$4.5 million	0
B	\$4.0 million	20
C	\$2.0 million	100

	SER	
A	30	100
B	25	60
C	15	0

Helicopter	MMH/FH	Relative Score
A	3	50
B	4	0
C	2	100

Relative scales have the additional advantage that alternatives can usually be scored much more directly and meaningfully on the actual criteria of interest without resorting to surrogate measures. This is so because the alternatives themselves define what is meant by such things as the best and worst reliability.

2.1.2.4 Relationships among scaling methods - Moving from an absolute scale to a ratio scale to a relative scale requires less and less information. The absolute scale requires definitions of both the unacceptable and ideal points. The ratio scale requires a definition of only the unacceptable point; the best alternative is used to define the highest point on the scale. The relative scale requires no definition of endpoints; both are determined by the alternatives under consideration. The relationships among the three scales are illustrated in Figure 2-2.

2.1.2.5 Weighting across criteria - A relationship also exists among the weights assigned to the criteria in the different methods of scaling. For example, suppose that the decision maker assesses his tradeoffs across the absolute scales using the following reasoning:

- Military Effectiveness is most important--as important as Cost and Reliability combined.

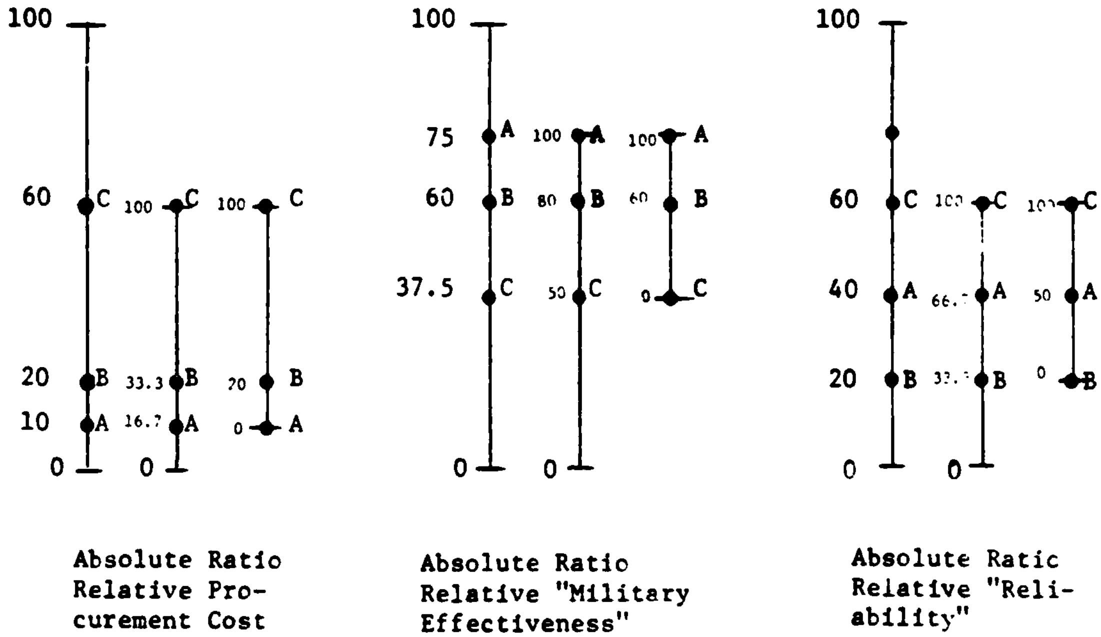


Figure 2-2

A COMPARISON OF ABSOLUTE, RATIO, AND RELATIVE VALUE SCALES

- Cost is least important--two thirds as important as reliability.

These two judgments specify a weighting of cost to military effectiveness to reliability equal to 20:50:30. Remember, what is being compared here is the relative importance of the varying performance on each criterion from an unacceptable level to an ideal level. If a decision maker were consistent in his judgments, he would specify a weighting of 12:37.5:18 for the ratio scale, because the range from unacceptable to the best helicopter is 60% of the absolute range on cost (.60 x 20 = 12), 75% of the absolute range on military effectiveness (.75 x 50 = 37.5) and 60% of the absolute range on reliability (.60 x 30 = 18). On the relative scale, the decision maker would specify a weighting of 10:18.75:12 because the range from the worst to the best helicopter is 50% of the absolute range on cost (.50 x 20 = 10), 37.5% of the absolute range on military effectiveness (.375 x 50 = 18.75), and 40% of the absolute range on reliability (.40 x 30 = 12). Calculations of normalized weights based on these proportions are shown in Table 2-1.

2.1.2.6 Evaluating alternatives - Evaluations are made by multiplying each alternative's score on a criterion by the corresponding weight and summing across criteria. These evaluations are shown in Table 2-2. Notice that, although the different scales give different numerical evaluations for the alternatives, helicopter A receives the highest evaluation by all methods. This result will always occur with any consistent set of scores and weights. Furthermore, the evaluation of helicopter C (the second best) relative to helicopters A and B (the best and worst) is exactly the same regardless of the evaluation method; that is, helicopter C's evaluation is about 76% of the distance between B's evaluation and A's evaluation. (Similar results would also hold for any other helicopters with intermediate

	Procurement Cost	"Military Effectiveness"	"Reliability"
Absolute	.20	.50	.30
Ratio	$\frac{(.2)(60)}{D_1} = .178$	$\frac{(.5)(75)}{D_1} = .555$	$\frac{(.3)(60)}{D_1} = .267$
Relative	$\frac{(.2)(60-10)}{D_2} = .245$	$\frac{(.5)(75-37.5)}{D_2} = .46$	$\frac{(.3)(60-20)}{D_2} = .295$

$$D_1 = (.2)(60) + (.5)(75) + (.3)(60) = 67.5$$

$$D_2 = (.2)(50) + (.5)(37.5) + (.3)(40) = 40.75$$

Table 2-1

A CONSISTENT SET OF NORMALIZED WEIGHTS

	Procurement Cost			"Military Effectiveness"			"Reliability"			Total Evaluations		
	A	B	C	A	B	C	A	B	C	A	B	C
Absolute	2	4	12	37.5	30	18.75	12	6	18	51.5	40	48.75
Ratio	3	5.9	17.8	55.5	44.4	27.78	17.8	8.9	26.7	76.4	59.2	72.28
Relative	0	4.9	24.5	46	27.6	0	14.75	0	29.5	60.75	32.5	54

(NOTE: $\frac{C-B}{A-B} \approx .76$ for all evaluation methods)

TABLE 2-2

EVALUATIONS OF THE HELICOPTERS

evaluations.) This is also a general feature of the three evaluation methods.

Some information, however, is lost in moving from an absolute scale to a ratio scale to a relative scale. (Recall that this loss of information is accompanied by a reduction in the required assessments.) Only the absolute evaluation gives information about how good the helicopters are when compared with the ideal. For instance, helicopter A is 52% as good as the ideal. Only the absolute and ratio evaluations can provide information on the percentage relationship among the alternatives. For instance, helicopter B is 78% as good as helicopter A. However, these kinds of comparisons, interesting though they may be, are not really necessary for a decision. Furthermore, the information required to make these comparisons is seldom worth its cost.

The comparability among the three evaluation methods is further demonstrated in Table 2-3. This table shows the simple conversions necessary to move from the absolute evaluation to either the ratio or relative evaluation, and those necessary to move from the ratio to the relative evaluation.

2.2 Description of the ASH Evaluation Model

2.2.1 Structure of the model - The top level of the model divides the evaluation into five main categories of value: Military Worth, Life Cycle Cost, Attainability, Force Structure Personnel Impact, and Rationalization, Standardization and Interoperability (RSI). This top-level structure is illustrated in Figure 2-3. The main categories of value are divided into subcategories to form a hierarchical arrangement, as shown.

The first main category of value, Military Worth, is divided into three subcategories: Operational

Conversions:

Conversion	Procurement Cost A	Procurement Cost B	Procurement Cost C	"Military Effectiveness" A	"Military Effectiveness" B	"Military Effectiveness" C	"Reliability" A	"Reliability" B	"Reliability" C	Total A	Total B	Total C
Absolute	$x_1 = 2$	4	12	$y_1 = 37.5$	30	18.75	$z_1 = 12$	6	18	$t_1 = 52$	40	49
Ratio	$x_2 = \frac{100x_1}{D_1} = 3$	5.9	17.8	$y_2 = \frac{100y_1}{D_1} = 55.6$	44.4	27.8	$z_2 = \frac{100z_1}{D_1} = 17.8$	8.9	26.7	$t_2 = 76$	59	72
Relative	$x_3 = \frac{100(x_1-2)}{D_2} = 0$	4.9	24.5	$y_3 = \frac{100(y_1-18.75)}{D_2} = 46$	27.6	0	$z_3 = \frac{100(z_1-6)}{D_2} = 14.7$	0	29.5	$t_3 = 61$	32	54
Relative	$x_3 = \frac{D_1}{D_2}(x_2-3) = 0$	4.8	24.5	$y_3 = \frac{D_1}{D_2}(y_2-27.8) = 46$	27.5	0	$z_3 = \frac{D_1}{D_2}(z_2-8.9) = 14.7$	0	29.5	$t_3 = 61$	32	54

Note: Numbers are rounded

Table 2-3

CONVERSIONS AMONG THE THREE EVALUATION METHODS

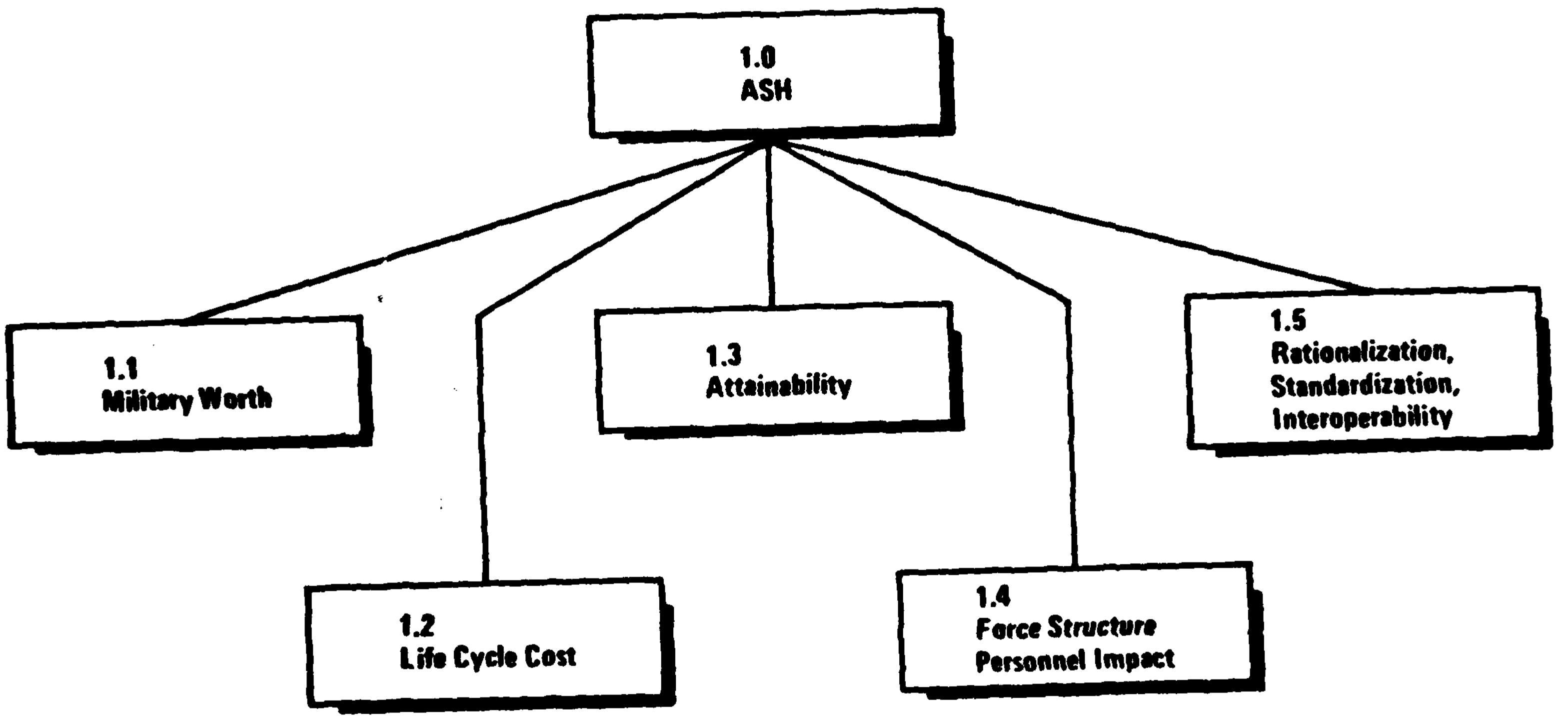


Figure 2-3

TOP-LEVEL STRUCTURE OF THE ASH EVALUATION MODEL

Acceptability, Technical Systems, and Technical System Risks. The first two subcategories represent complete evaluations of the ASH candidates from the points of view of the users and the technical community. The third category represents the risks involved in achieving the ASH candidates.

This particular subdivision of Military Worth was chosen to accommodate the different points of view held by users and technical experts. Each community is allowed to evaluate the candidates in a way that seems most natural, and neither is forced to adopt the other's way of thinking. While this structure may result in very different evaluations of the candidates by the different groups (which, for the most part, did not happen in this application), the structure also allows for a specific identification of the reasons for the differences. By including Technical System Risks at this level in the hierarchy, both groups' evaluations can be adjusted to reflect the degree to which the ability to achieve the promised level of performance of each candidate is uncertain.

This particular division of the Military Worth category is illustrated in Figure 2-4. Each of the categories within Military Worth is also subdivided. The Operational Acceptability category is divided according to the way that the user community makes its evaluation. The Technical Systems category is divided in the manner in which the engineers and designers evaluate the candidates. Technical Systems Risk is divided according to the main systems of the helicopters that are considered for modification and, therefore, those that entail the greatest degree of risk. These subdivisions are also shown in Figure 2-4.

Operational Acceptability is subdivided into three main areas: Operational Effectiveness, Availability, and Training. Operational Effectiveness provides a measure

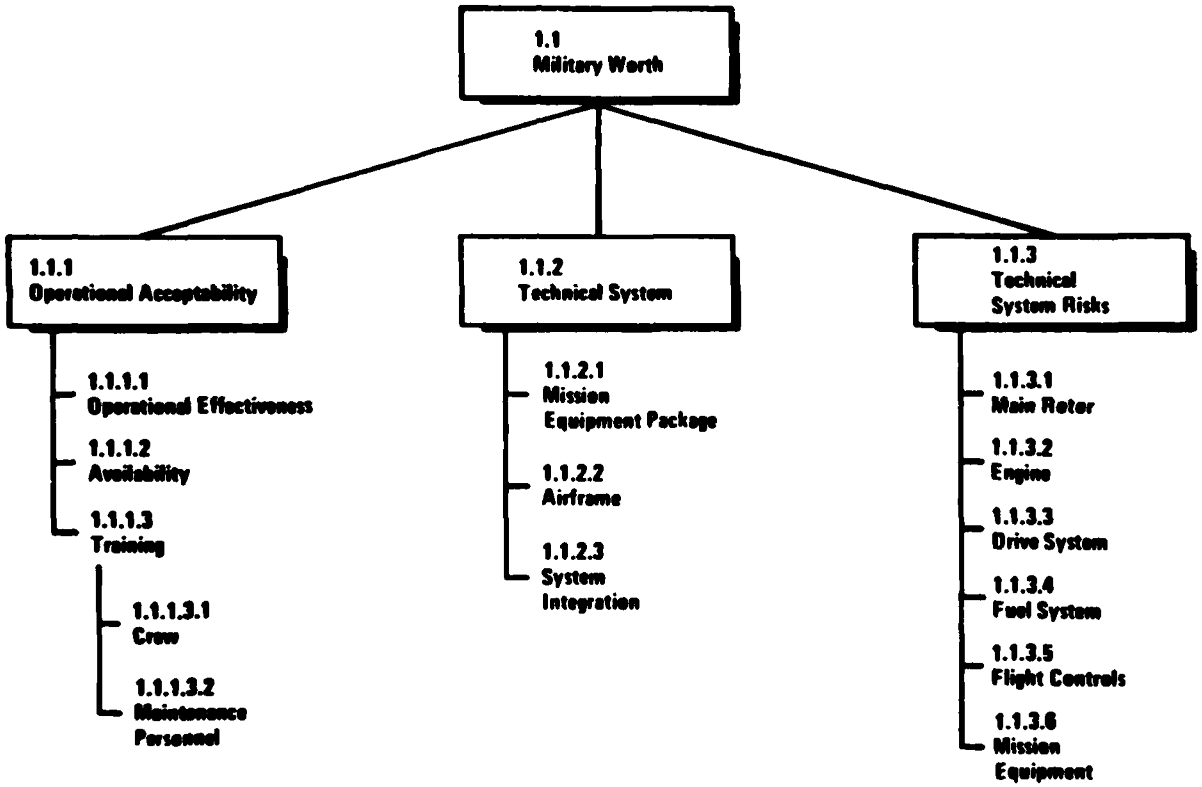


Figure 2-4

SUBDIVISIONS OF THE MILITARY WORTH CATEGORY of how well each candidate performs the scout missions. Such a measure is based both on the results of large-scale simulations (in which five helicopter designs were used to represent the thirteen ASH candidates), and direct judgmental evaluations of the performance of the candidates in the major scout missions (considering those functions that are important to each mission). Subdivisions of Operational Effectiveness are detailed in Figure 2-5. While Operational Effectiveness measures the performance of the candidate when it is in action, Availability measures the aspects that are important to keeping each helicopter ready for action. Subdivisions of Availability are detailed in Figure 2-6. The area of Training is subdivided by the type of personnel involved--the helicopter's crew and maintenance personnel.

Value from a Technical System standpoint is subdivided according to the main types of systems (mission equipment and airframe) and the degree to which ASH candidates integrate the systems effectively. Detailed subdivisions of the Technical Systems are are shown in Figure 2-7.

The second main category of value is Life Cycle Cost (LCC). Subdivisions of LCC correspond to the timing of the cost as well as the specific type of funding required. Thus, LCC is divided into Acquisition Cost and Ownership Cost. Acquisition Cost, in turn, is divided into RDT&E Cost and Procurement (APA) Cost. Ownership Cost is divided into other anticipated investments and Operations & Support. Subdivisions of LCC are shown in Figure 2-8.

The third main category of value is Attainability. This category measures the degree to which each ASH candidate is affordable and is able to meet schedule constraints. Affordability mainly concerns the relationship

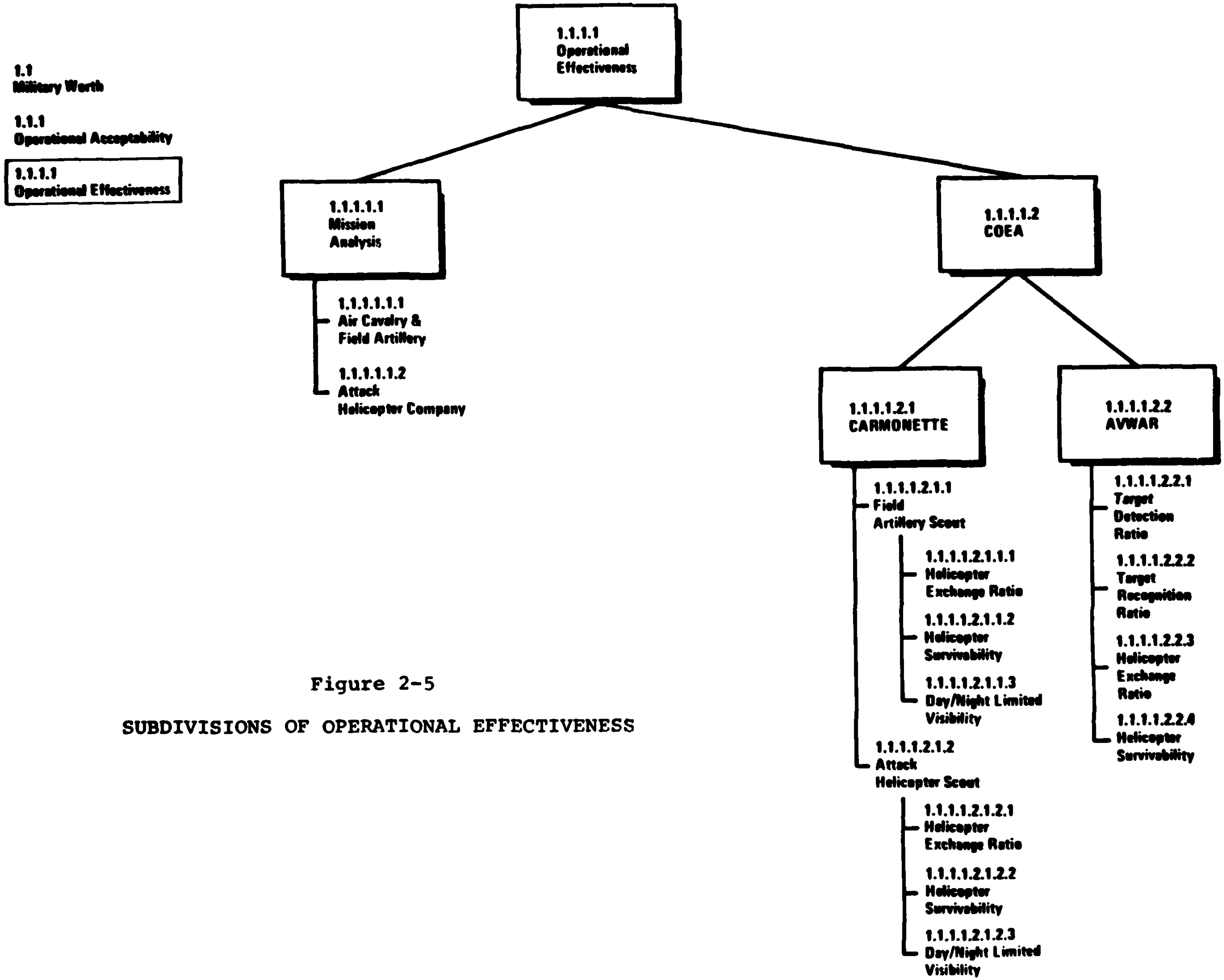


Figure 2-5

SUBDIVISIONS OF OPERATIONAL EFFECTIVENESS

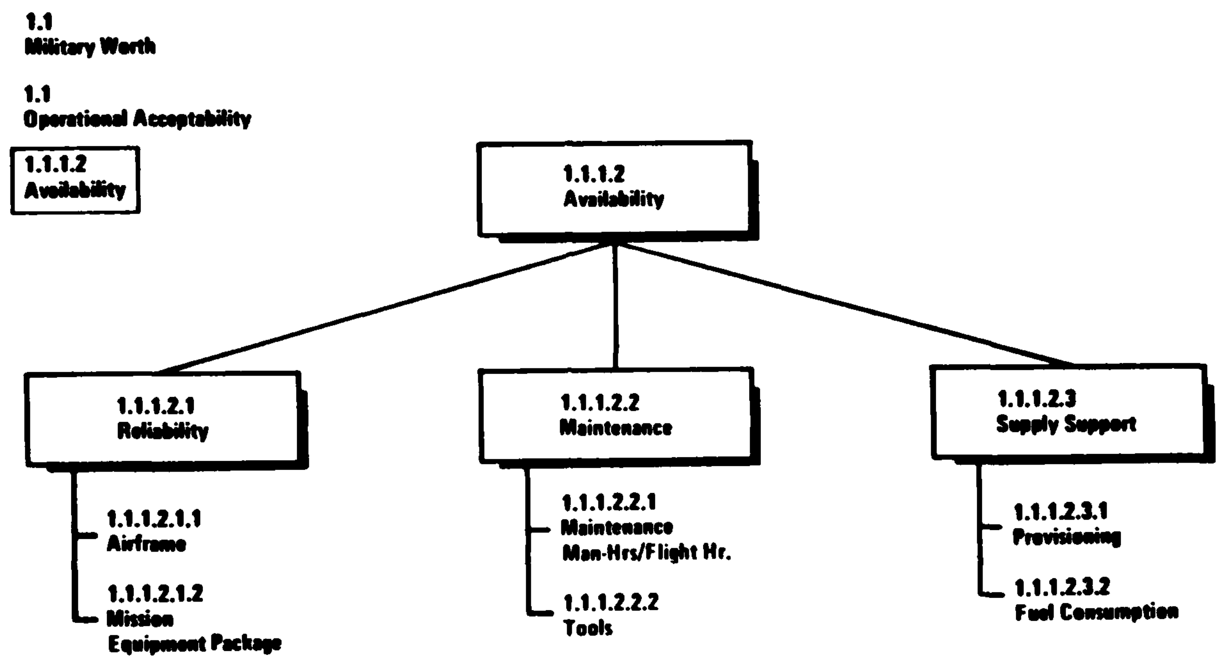


Figure 2-6

SUBDIVISIONS OF AVAILABILITY

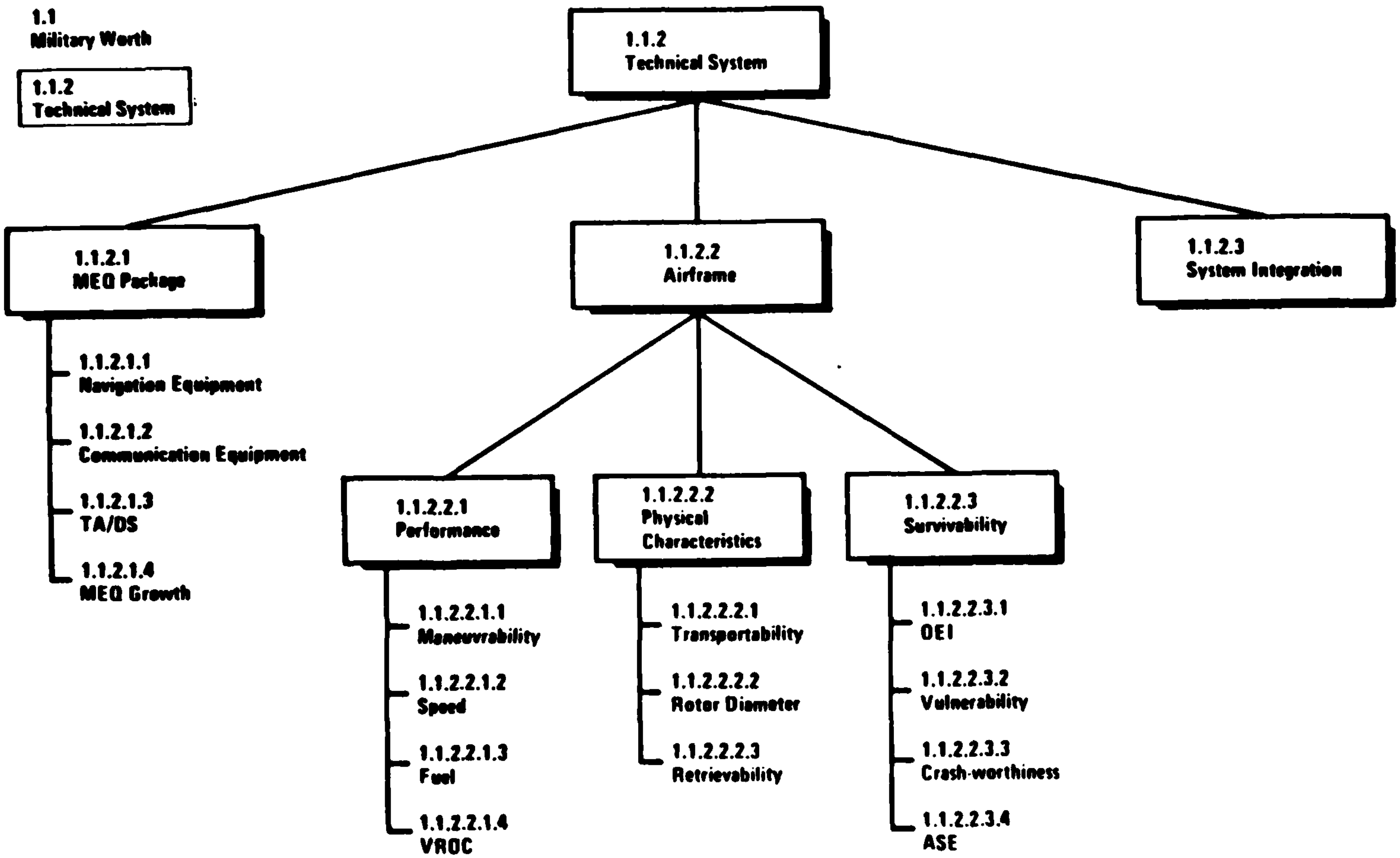


Figure 2-7

SUBDIVISIONS OF TECHNICAL SYSTEMS

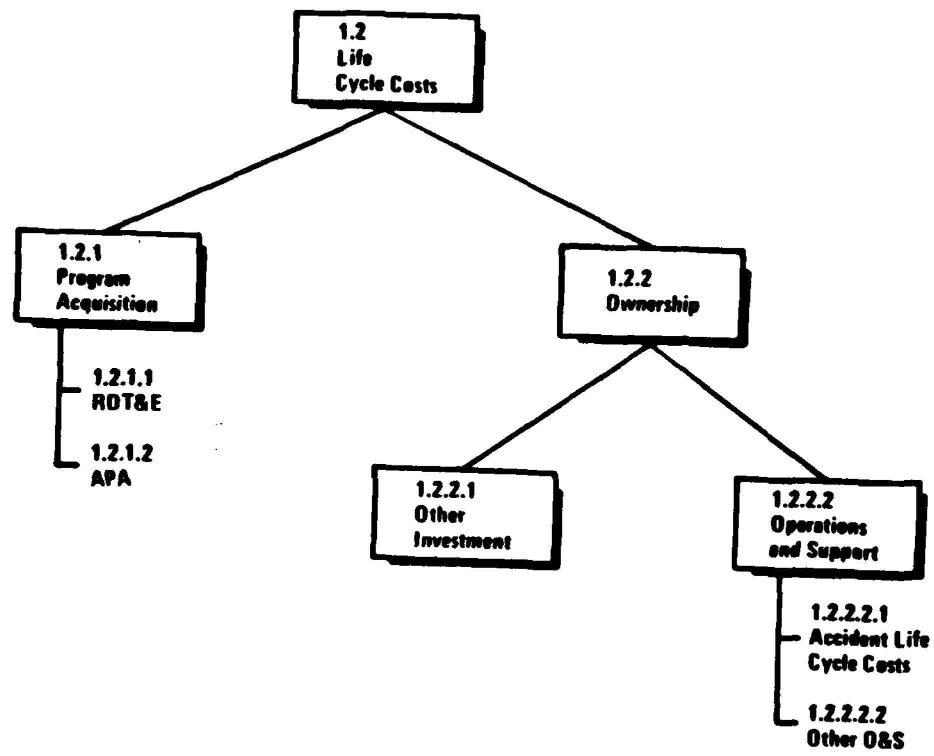


Figure 2-8

SUBDIVISIONS OF LIFE CYCLE COSTS

between each candidate's funding requirement and the availability of funds as reflected in the Army's latest Program Objectives Memorandum (POM). The Schedule subcategory concerns each candidate's ability to meet the Initial Operational Capability (IOC) mandated by Congress as well as its entire production schedule. Both the cost estimates and schedule estimates are adjusted by their riskiness, as reflected in the third subcategory. Subdivisions of Attainability are detailed in Figure 2-9.

The fourth main category of value, Force Structure Personnel Impact, reflects the increased personnel requirements of the ASH candidates.

Rationalization, Standardization, and Interoperability, the final main category of value, is concerned with the possibilities for joint development and production of ASH candidates with allies (especially NATO allies) and the ability of the ASH candidates to perform missions in conjunction with allied military units. Details of the subdivisions of this category are shown in Figure 2-10.

2.2.2 <u>Assessed inputs to the ASH Evaluation Model</u> - The ASH alternatives are evaluated by using a relative scoring model, as explained in Sections 2.1.1 and 2.1.2. Since detailed displays of all inputs to the model are given in the computer printouts in Appendices A and B, selected inputs are highlighted in the following paragraphs.

Most of the subcategories of value (the bottom-level branches in the structure described in Section 2.2.1) are areas of interest that are not readily quantifiable on an

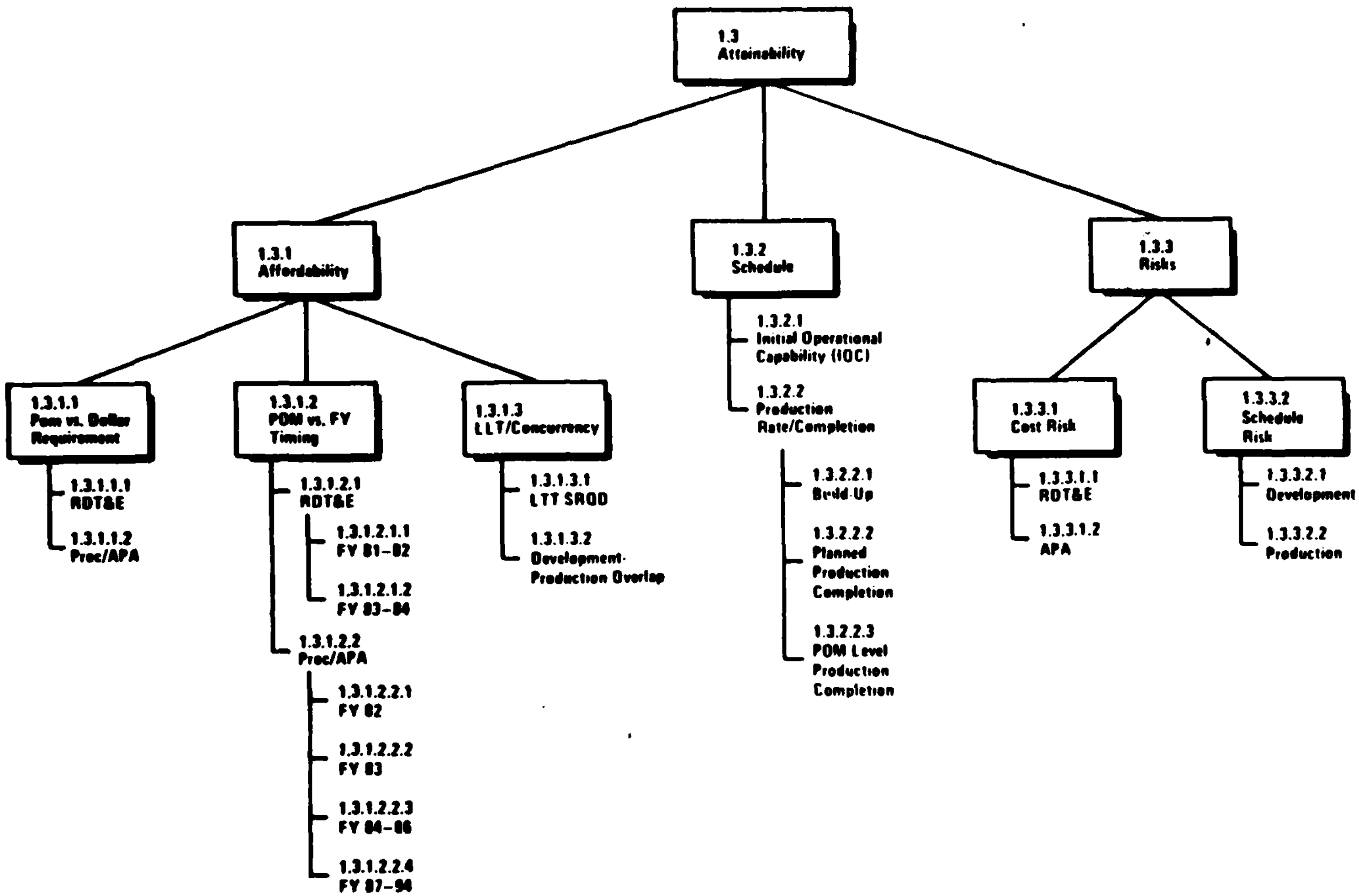


Figure 2-9

SUBDIVISIONS OF ATTAINABILITY

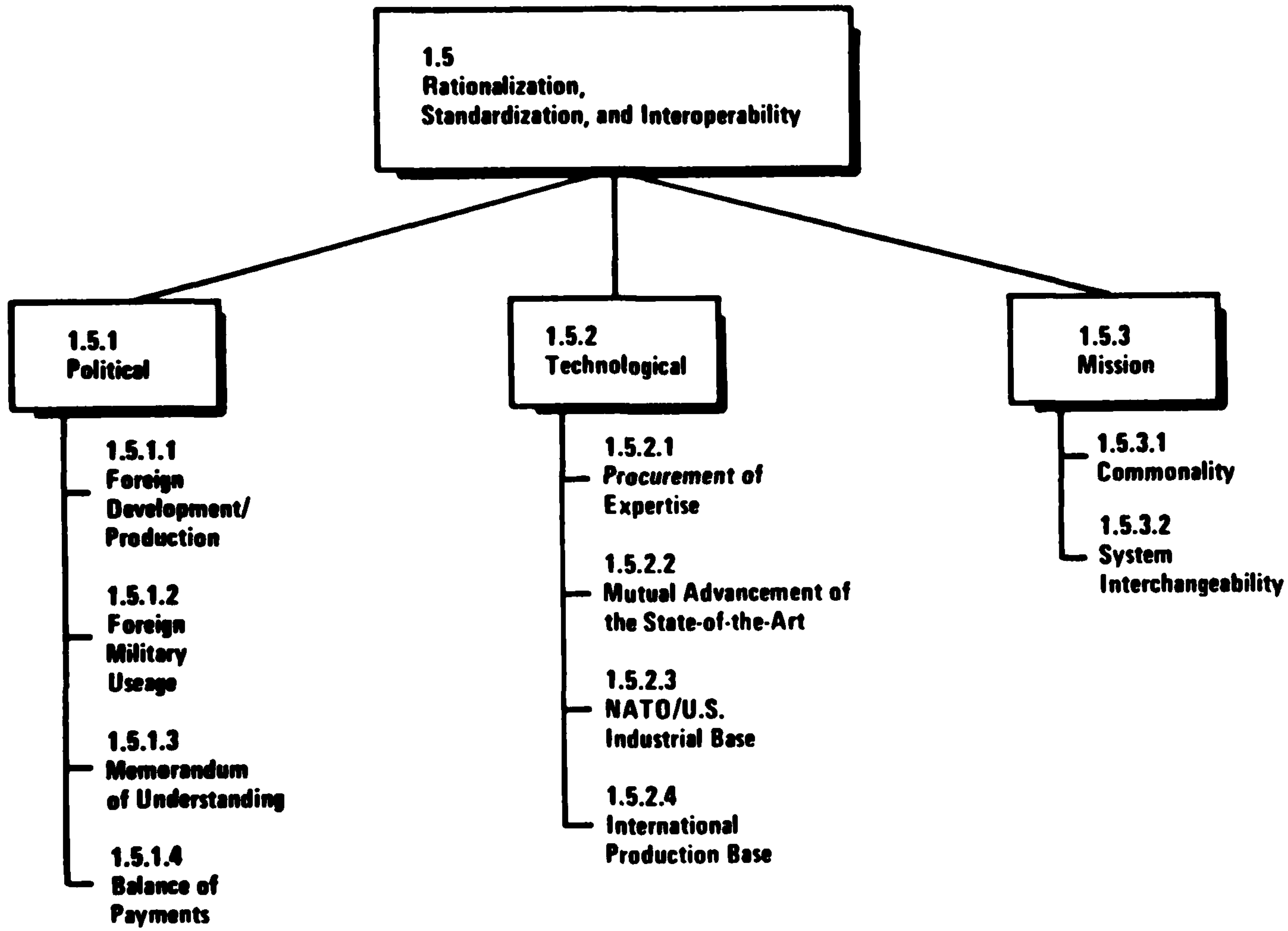


Figure 2-10

SUBDIVISIONS OF RATIONALIZATION, STANDARDIZATION, AND INTEROPERABILITY underlying scale. For example, consider the following path in the structure (from Figures 2-4 and 2-7):

Military Worth
 Technical Systems
  Mission Equipment Package
   Target Acquisition/Designation System.

This path is entry level 1.1.2.1.3 in the model. The technical appraisal of the value of various target acquisition/designation systems (TA/DS) is based directly on the quality of the equipment involved. Quality is determined by such factors as:

- the types of sensors used;
- the survivability of the system based on its mounting location (mast-mounts are more survivable than nose-mounts);
- the range of the sensors; and
- the capability of the sensors under condition of limited visibility (especially night operations.

Considering these factors, seven of the thirteen ASH candidates are judged to have the best TA/DS: BTA, 350, 129, BT2, BTT, OHM, and B4K. These seven systems are all assigned scores of 100. The OH-58C is judged to have the worst TA/DS and is assigned a score of zero. Other candidates have intermediate levels of performance on TA/DS and are scored accordingly. For instance, the improvement in TA/DS on the OH-58D over the OH-58C is assessed to be about 40% of the BTA's improvement, so the OH-58D receives a score of 40. Similar reasoning leads to the scores for the other ASH candidates given in Table 2-4. (Detailed rationale for each score is given in Appendix B.)

1.1.2.1 - ASH - MIL WORTH - TECH SYS - MED PKG

FACTOR	WT	BTA	350	129	OHT	58E	500	58D	064	B12	BTT	OHm	B4K	53C
3) TA/DS		100	100	100	60	80	40	40	60	100	100	100	100	0

Table 2-4

SCORES FOR ASH CANDIDATES ON TA/DS

Of course, some of the entry-level branches in the structure lend themselves to quantification on the basis of some natural unit, such as dollars for cost. In these cases, estimates can be made on the natural scales and then transformed to relative scales for consistency. For example, estimates of the APA (procurement) costs for the candidates range from a low of $138,000 per unit for the OH-58C to a high of $3.857 million for the OH-64. (Cost estimates are "most likely" costs based on "prime quantity" orders, generally 1472, stated in fiscal year 1980 dollars.) The relative scores for these candidates are then 100 for the OH-58C, to signify that it has the most-preferred cost, and 0 for the OH-64. Other ASH candidates are scored at intermediate levels in proportion to their costs.

The next task in working up through the hierarchy is to trade off the scores across the criteria. In this operation, the importance of the range of impact of the candidates on one criterion is traded off against the importance of the range of impacts on other criteria. These trade-offs are expressed as weights assessed for each criterion.

Consider the category of Mission Equipment Packages, which is the aggregation of navigation, communications, and TA/DS equipment, together with equipment growth possibilities. The following line of reasoning leads to the weights assessed for each criterion as displayed in Table 2-5:

- The range of impacts of the ASH candidates on TA/DS is most important.

- The range of impacts on TA/DS is as important as the impacts on Navigation and Communications combined.

1.1.2.1 - ASH - MIL WORTH - TECH SYS - MEQ PKG

	FACTOR	WT	BTA	350	129	OHT	58E	500	58D	D64	BT2	BTT	OHM	B4K	58C
1)	NAV	*(25)	80	80	80	80	50	0	0	100	80	80	80	80	10
2)	COMMS	*(20)	100	100	100	100	100	20	20	80	100	100	100	100	0
3)	TA/DS	*(45)	100	100	100	60	80	40	40	60	100	100	100	100	0
4)	MEQ GROWTH	*(10)	80	0	60	60	0	0	0	100	80	80	60	80	0
	TOTAL		93	85	91	73	68	22	22	78	93	93	91	93	3

Table 2-5

TRADE-OFFS ACROSS MISSION EQUIPMENT SUB-CATEGORIES

- o The improvement of BTA's communications equipment over 58C's communications equipment is equally as important as the improvement of BTA's navigation equipment over 500's navigation equipment.

- o The range of impacts on Growth is one-half as important as the range of impacts on Communications.

These relationships establish the set of weights for the criteria shown in Table 2-5 (the weights are normalized to add to 100% for consistency.)

The total evaluation of each candidate in the category of Mission Equipment is obtained by taking a weighted-average of the candidate's scores in the subcategories. For example, BTA's total evaluation is calculated as follows:

$$(.25)(80) + (.20)(100) + (.45)(100) + (.10)(80) = 93.$$

These weighted-average evaluations are combined, in a similar manner, with weighted-average evaluations from other categories to arrive at evaluations at higher levels in the structure.

Table 2-6 shows the evaluations of the candidates on each major category of value. At least two types of analysis can be done with these evaluations: trade-off weights could be assessed across the major categories to arrive at a single "best" candidate, or the evaluations on certain categories (such as Military Worth) could be plotted against cost to identify the efficient set of candidates--those that provide the most benefit at different levels of cost.

1 - ASH

FACTOR	BTA	350	129	OHT	58E	500	58D	064	BT2	BTT	OHM	B4K	58C
1) MIL WORTH	76	71	72	51	61	39	36	60	77	79	69	80	24
2) LCC	49	48	45	49	64	73	83	11	39	39	41	38	97
3) ATTAINABTY	32	23	23	44	45	57	84	66	26	26	25	26	96
4) FOR ST IMP	75	92	43	5	100	98	98	0	50	50	0	50	98
5) RSI	69	72	91	9	15	44	6	12	69	69	9	69	0

Table 2-6

EVALUATIONS AT EACH MAJOR CATEGORY

Table 2-7 displays the overall evaluations of the ASH candidates based on the following assessment of weights:

Military Worth 50%
Life Cycle Cost 30%
Attainability 15%
Force Structure Personnel Impact 3%
Rationalization, Standardization, & Interoperability 2%.

Overall evaluations now range from a high of 61 points for the BTA to a low of 43 for the OH-64. So, with these trade-offs across criteria, BTA is the preferred candidate.

Rather than make all of these trade-offs across the five top-level categories of value, one might wish to examine the efficiency of the candidates as a function of one of the categories. Of particular interest is the plot of Military Worth, Attainability, Force Structure Personnel Impact, and RSI (weighted in the same proportion as in Table 2-7) versus Utility for Life Cycle Cost. Such a plot allows identification of the most "beneficial" candidates at various levels of "cost," where "cost" is determined by weighting dollar costs of different categories (such as RDT&E cost) according to the importance of saving money in each category (as reflected in the weights assigned to each cost category, see Appendix A). Plotting these values leads to Figure 2-11.

Figure 2-11 is arranged so that the efficient ASH candidates are those appearing on the upper left (or northwest) edge of the plot. These candidates are the BTA, OH-58E, OH-58D, and OH-58C. (Recall that utilities for cost are assigned so that low costs receive high scores on 0-to-100 scales. Thus, the transformation of 100-Cost Utility

1 - ASH

	FACTOR	WT	BTA	350	129	OHT	58E	500	58D	064	BT2	BTT	OHM	B4K	58C
1)	MIL WORTH	(50)	76	71	72	51	61	39	36	60	77	79	69	80	24
2)	LCC	(30)	49	48	45	49	64	73	83	11	39	39	41	38	97
3)	ATTAINABTY	(15)	32	23	23	44	45	57	84	66	26	26	25	26	96
4)	FOR ST IMP	*(3)	75	92	43	5	100	98	98	0	50	50	0	50	98
5)	RSI	(2)	69	72	91	9	15	44	6	12	69	69	9	69	0
	TOTAL		61	57	56	47	60	54	56	43	57	58	50	58	58

Table 2-7

OVERALL EVALUATIONS OF ASH CANDIDATES

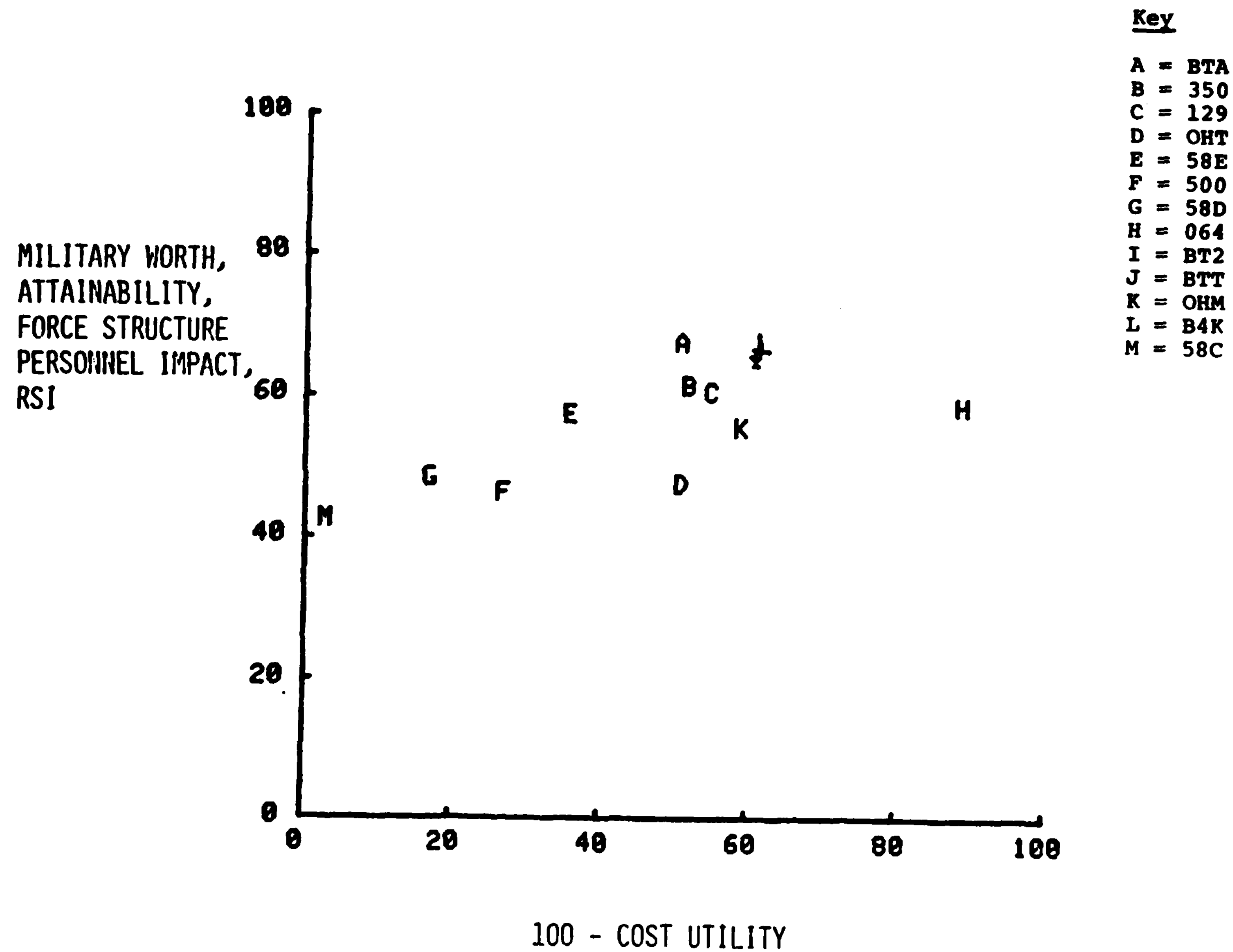


Figure 2-11

VALUES OF ASH CANDIDATES VERSUS COST

coordinates low scores with low costs). The following reasoning explains why these efficient candidates dominate the others:

- o BTA is both better and cheaper than 350, 129, BT2, BTT, OHM, and 064.
- o BTA is cheaper than B4K and both provide equal benefit.
- o 58E is better and cheaper than OHT.
- o 58D is better and cheaper than 500.

A similar plot results when dollar cost (rather than cost utility) is plotted on the horizontal axis or when Military Worth alone is plotted on the vertical axis. Figure 2-12 shows the plot that results when both of these changes are made. The only differences in the efficient candidates are that the 500 and the B4K become efficient when benefit is determined by just Military Worth, and equal-dollar costs of all categories are weighted equally.

An interesting and important feature of both Figures 2-11 and 2-12 is that the efficient candidates almost lie on a straight line. This feature is important because it means that all of the efficient candidates are about equally efficient; that is, "you get what you pay for." In such a case, the required level of benefit or the amount of money available might be the best determinant of the "optimal" candidate.

2.2.3 <u>Sensitivity analyses</u> - Numerous sensitivity analyses were conducted during the course of this study. These analyses were aimed at determining the assessments

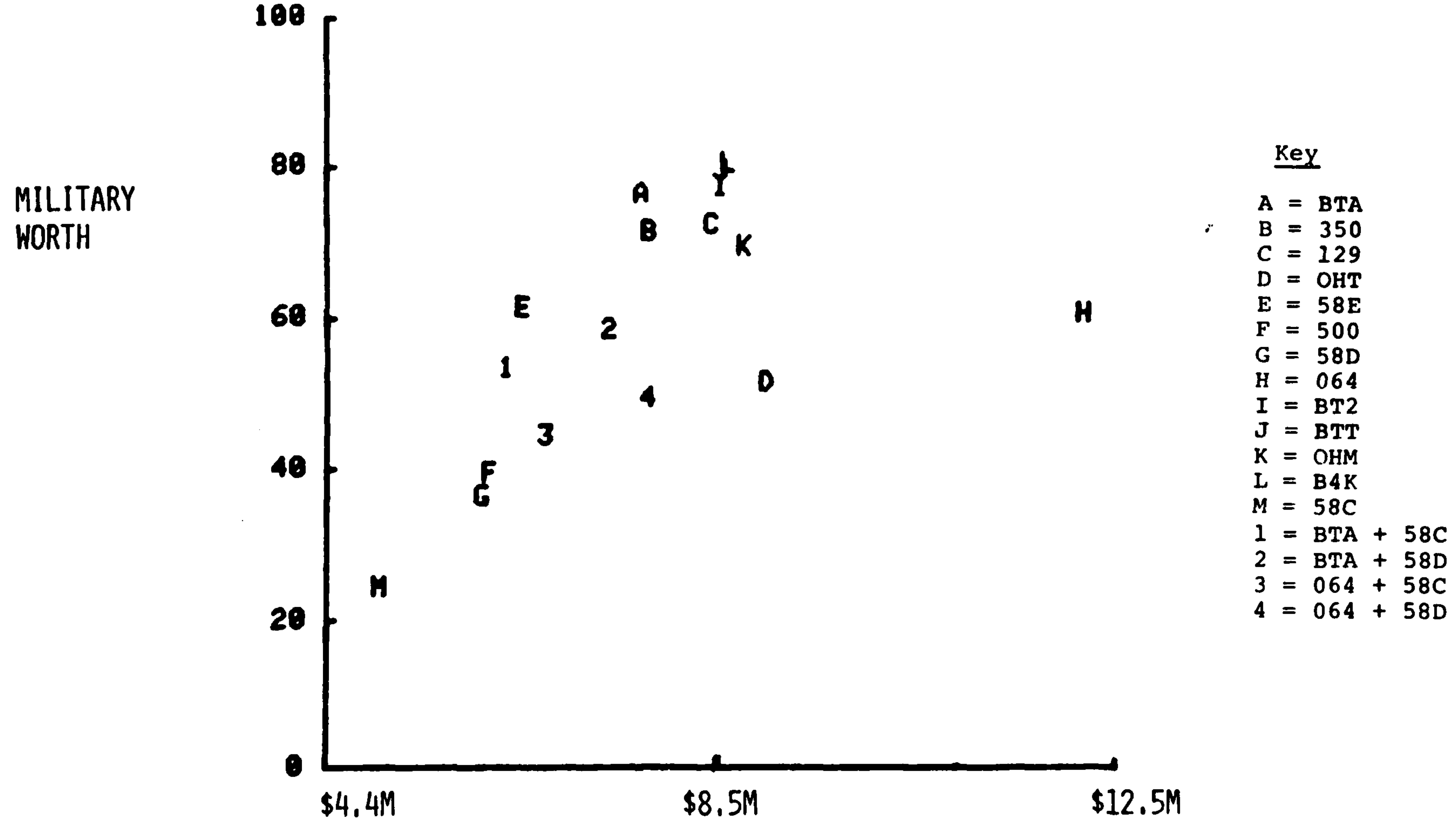


Figure 2-12
MILITARY WORTH VERSUS COST

of both scores and weights in the model that most critically drove the results; this was done as a way to identify improvements in the model. These analyses involved changes in both the scores of the alternatives on criteria and the weights across the criteria. Since the results of the analyses led, for the most part, to refinements of the model's inputs and structure that made older versions of the model obsolete, few records were kept of the analyses; and the discarded models are of little interest. For these reasons, we will not attempt to reconstruct those analyses but instead will present a few illustrative examples.

One type of sensitivity analysis examines the effects on the overall evaluations of changes in the weight assigned to a particular criterion. For example, Table 2-8 shows the results of varying the weight assigned to Military Worth. At the current weight, 50%, the alternatives receive the same evaluations shown in Table 2-7. In particular, BTA receives the highest overall evaluation, 61 points. These evaluations are displayed on the row labeled 50.0 on Table 2-5, and BTA's highest evaluation is marked with an asterisk. Table 2-8 shows that BTA receives the highest evaluation as long as the weight assigned to Military Worth remains between 50% and 70%. For weights above 70%, B4K is best and for weights at or below 40%, 58C is best. Since B4K scores highest in Military Worth, it is not surprising that B4K is most preferred when the weight assigned to Military Worth is very high. Similarly, 58C is best on the composite of everything except Military Worth (most importantly Life Cycle Costs), so it is no surprise that it is preferred for low weights on Military Worth.

Analyses of this type can also be performed at other levels in the structure. For example, Table 2-9 shows the sensitivity of the evaluations to changes in the weight assessed for Mission Equipment Packages. In this table, the

1.1 MIL WORTH CURRENT CUMWT: 50.00

WT	BTA	350	129	OHT	58E	500	58D	064	BT2	BTT	OHM	B4K	58C
.0	46	44	40	43	59	68	81	27	37	37	32	36	93*
10.0	49	47	43	44	59	65	77	30	41	41	36	41	86*
20.0	52	49	46	45	59	63	72	34	45	46	40	45	79*
30.0	55	52	49	46	59	60	67	37	49	50	43	49	72*
40.0	58	55	53	47	60	57	63	40	53	54	47	54	65*
50.0	61*	57	56	47	60	54	58	43	57	58	50	58	58
60.0	64*	60	59	48	60	51	54	47	61	62	54	62	51
70.0	67*	63	62	49	61	48	49	50	65	67	58	67*	44
80.0	70	65	65	50	61	45	45	53	69	71	61	71*	37
90.0	73	68	68	51	61	42	40	57	73	75	65	75*	31
100.0	76	71	72	51	61	39	36	60	77	79	69	80*	24

Table 2-8

SENSITIVITY OF OVERALL RESULTS TO CHANGES IN THE WEIGHT ASSIGNED TO MILITARY WORTH

1.1.2.1 MEQ PKG CURRENT CUMWT: 13.50

WT	BTA	350	129	OHT	58E	500	58D	064	BT2	BTT	OHM	B4K	58C
.0	56	53	50	43	59	59	64	38	52	53	44	53	67*
5.0	58	55	52	45	59	57	62	40	54	55	46	55	64*
10.0	60*	56	54	46	60	55	60	42	56	57	49	57	60*
15.0	62*	58	56	48	60	53	58	44	58	59	51	59	57
20.0	64*	60	58	49	61	51	56	46	60	61	53	61	54
25.0	66*	61	60	51	61	50	54	48	62	63	56	63	51
30.0	67*	63	62	52	62	48	51	50	64	65	58	65	48
35.0	69*	64	65	54	62	46	49	52	66	67	61	67	44
40.0	71*	66	67	55	63	44	47	54	68	69	63	69	41
45.0	73*	67	69	57	63	42	45	56	70	71	65	71	38
50.0	75*	69	71	58	64	40	43	58	72	73	68	73	35

Table 2-9

SENSITIVITY OF OVERALL RESULTS TO CHANGES IN THE WEIGHT ASSIGNED TO MISSION EQUIPMENT PACKAGE

cumulative weight assigned to Mission Equipment, which is calculated by multiplying all of the weights down the path in the structure, is varied from 0 to 50% of the total in the model (its current weight is 13.5%.) Within this range of variation, the preferred candidate shifts from 58C, for very low weights, to BTA for higher weights.

Sensitivity of the evaluations to changes in other inputs, such as combinations of weights and scores, can be readily determined by entering new values and having the computerized model calculate the new evaluations. This type of analysis was done for a variety of changes during the course of the project.

Another type of analysis also proves useful: a discrimination analysis that identifies and sorts the differences between candidates that contribute to the differences in their evaluations. Table 2-10 displays such a comparison of the OH-58D and the Hughes 500D (comparisons of other pairs of candidates are given in Appendix C). This analysis shows that the most important single discriminator favoring the OH-58D is APA (procurement) cost, which contributes 4.2 points to the overall difference between the two candidates. Reading down the list, one sees that many of the subcategories of Attainability also favor the 58D, as do the cost subcategories of Accident Life Cycle Cost and Other Investment Cost. In the middle range of the chart are displayed all of the subcategories in which the performance of the two candidates is the same. These include most of subcategories of Military Worth. The subcategories in which the 500 is preferred to the 58D are given at the bottom of the table. Most important of these is Other Operations and Support Cost, which favors the 500 by 1.7 overall points. Other major differences favoring the 500 include subcategories of the technical performance of the airframe and most subcategories of RSI.

	(WT)	NTA	350	129	OHT	58E	500	58D	064	FLG	DISCR
1.2.1.2 - APA	(85)	45	44	35	49	61	64	86	0		4.21
1.3.1.1.2 - PROC/APA	(85)	18	18	8	26	44	50	93	37		1.05
1.3.1.2.2.2 - FY83	(40)	100	100	100	0	0	0	100	0		.76
1.3.2.1 - IOC	(65)	25	0	0	80	80	80	100	100		.68
1.3.1.2.2.1 - FY82	(30)	100	100	100	100	0	0	100	0		.57
1.3.1.2.2.3 - FY84-86	(20)	30	10	0	20	10	20	100	0		.31
1.3.1.3.1 - LLT PROD	(50)	40	40	20	0	40	40	80	20		.30
1.2.2.2.1 - ACQ LCC	(15)	97	89	90	64	65	65	88	0		.23
1.3.2.2.3 - POM LEV PR	(35)	10	10	10	30	50	65	100	65		.23
1.3.3.1.2 - APA	(50)	15	15	6	36	50	54	85	67	58D	.19
1.2.2.1 - OTHER INV	(10)	63	63	60	85	76	78	99	0	IS	.16
1.2.1.1 - PDTAE	(15)	7	8	57	72	20	77	81	100	BETTER	.13
1.3.1.3.2 - DEV PROD O	(50)	75	50	50	0	75	75	90	90		.11
1.3.3.2.2 - PROD	(40)	30	0	30	0	30	50	75	30		.10
1.1.1.3.2 - MAINT	(40)	25	20	10	50	45	55	70	0		.07
1.1.1.2.3.1 - PROVISIONG	(40)	30	0	0	85	50	70	85	60		.04
1.1.3.4 - FUEL SYS	(5)	0	0	0	90	90	90	100	100		.02
1.3.3.1.1 - RDTAE	(50)	13	0	42	78	21	79	83	100		.02
1.3.1.2.2.4 - FY87-94	(10)	0	15	15	15	70	60	70	100		.02
1.3.1.1.1 - PDTAE	(15)	7	7	57	72	18	77	80	100		.02
1.1.1.2.2.2 - TOOLS	(15)	45	0	0	70	60	75	80	65		.01
1.1.1.1.1.1 - AC & FA	(45)	85	75	80	40	60	25	25	50		.00
1.1.1.1.1.2 - AHC	(55)	90	80	80	35	65	30	30	45		.00
1.1.1.1.2.1.1.1 - HELO EX RT	(20)	0	0	0	0	0	0	0	0		.00
1.1.1.1.2.1.1.2 - HELO SURVI	(30)	0	0	0	0	0	0	0	0		.00
1.1.1.1.2.1.1.3 - D/N/LIM VS	(50)	0	0	0	0	0	0	0	0		.00
1.1.1.1.2.1.2.1 - HELO EX RT	(20)	100	100	100	15	100	16	16	0		.00
1.1.1.1.2.1.2.2 - HELO SURV	(30)	100	100	100	0	100	79	79	0		.00
1.1.1.1.2.1.2.3 - D/N/LIM VS	(50)	86	86	86	100	71	0	0	100		.00
1.1.1.1.2.2.1 - TG DET RAT	(25)	100	100	100	84	100	0	0	70		.00
1.1.1.1.2.2.2 - TG REC RAT	(25)	0	0	0	100	0	100	100	100		.00
1.1.1.1.2.2.3 - HELO EX RT	(25)	100	100	100	2	100	15	15	33		.00
1.1.1.1.2.2.4 - HELO SURV	(25)	100	100	100	21	100	67	67	25		.00
1.1.1.2.2.1 - MMH/FH	(85)	59	79	32	1	100	97	97	1		.00
1.1.1.2.3.2 - FUEL CONSM	(60)	90	90	40	60	90	100	100	0		.00
1.1.1.3.1 - CREW	(60)	57	56	47	37	85	100	100	0		.00
1.1.2.1.1 - NAV	(25)	80	80	80	80	50	0	0	100		.00
1.1.2.1.2 - COMMS	(20)	100	100	100	100	100	20	20	80		.00
1.1.2.1.3 - TA/DA	(45)	100	100	100	60	80	40	40	60		.00
1.1.2.1.4 - MEQ GROWTH	(10)	80	0	60	60	0	0	0	100		.00
1.1.2.2.1.3 - FUEL	(20)	90	90	40	60	90	100	100	0		.00
1.1.2.2.2.1 - TRANSABILTY	(14)	65	75	0	50	85	85	85	100		.00
1.1.2.2.2.3 - RETRIEVBTY	(29)	100	100	90	50	100	100	100	0		.00
1.1.2.2.3.1 - DET	(20)	0	0	80	0	0	0	0	80		.00
1.1.2.2.3.2 - VULNERABLTY	(40)	60	40	40	5	30	25	25	40		.00
1.1.2.2.3.4 - ASE	(20)	50	50	50	50	50	0	0	100		.00
1.1.2.3 - SYS INT	(10)	100	95	95	60	0	10	10	50		.00
1.1.3.1 - MAIN ROTOR	(10)	0	50	40	100	80	100	100	100		.00
1.1.3.2 - ENGINE	(15)	0	0	70	50	70	100	100	100		.00
1.1.3.3 - DRIVE SYS	(15)	0	50	75	90	60	100	100	100		.00
1.1.3.5 - FLGHT CONT	(5)	0	80	50	100	75	100	100	100		.00
1.3.1.2.1.1 - FY81-82	(60)	0	0	100	100	0	100	100	100		.00
1.3.1.2.1.2 - FY83-86	(40)	0	15	50	100	15	100	100	100		.00
1.3.2.2.1 - BUILD-UP	(20)	0	0	0	30	30	30	30	100		.00
1.3.3.2.1 - DEV'T	(60)	75	45	0	97	75	95	95	100		.00
1.4 - FOR ST IMP	(3)	75	92	43	5	100	96	98	0		.00
1.5.2.2 - ADV SOA	(25)	100	20	30	0	0	0	0	0		.00
1.5.2.3 - INDUS BASE	(25)	100	80	60	0	0	0	0	0		.00
1.5.3.2 - SYS INTRCH	(50)	100	60	100	25	25	25	25	25		.00
1.5.2.1 - PROD EXPER	(25)	50	100	35	0	0	20	0	15		-.02
1.5.3.1 - COMMONALTY	(50)	100	0	100	0	0	30	0	0		-.06
1.5.1.4 - BAL OF PAY	(10)	50	100	100	15	15	50	0	15		-.06
1.1.1.2.1.2 - MEP	(45)	20	0	10	25	30	50	40	30		-.06
1.5.2.4 - PROD BASE	(25)	100	100	100	25	25	100	25	25		-.07
1.5.1.2 - FOR MIL US	(30)	50	50	100	25	25	35	10	30		-.09
1.5.1.3 - MOU	(10)	80	100	100	0	0	90	0	20		-.11
1.1.3.6 - MISS EQUIP	(50)	0	0	0	70	30	90	85	100	500	-.13
1.1.2.2.3.3 - CRASH-WHT	(20)	100	100	75	25	0	35	0	70	IS	-.18
1.1.2.2.1.2 - SPEED	(10)	89	60	90	60	58	62	0	89	BETTER	-.20
1.1.2.2.2.2 - ROTOR DIA	(57)	70	60	40	20	60	100	60	0		-.22
1.3.2.2.2 - PLND PROD	(45)	30	30	30	0	0	30	0	100		-.25
1.1.1.2.1.1 - A/E	(55)	100	60	50	0	30	45	10	55		-.26
1.5.1.1 - FOR DV PRH	(50)	55	100	100	0	20	60	0	0		-.36
1.1.2.2.1.4 - VROC	(40)	75	65	65	50	50	30	0	82		-.39
1.1.2.2.1.1 - MANUVRABTY	(30)	100	80	50	0	90	50	0	50		-.49
1.2.2.2.2 - OTHER O&S	(85)	77	76	60	28	100	100	70	0		-1.72

Table 2-10

A DISCRIMINATION ANALYSIS BETWEEN 58D AND 500

Comparisons such as the one in Table 2-10 can be used in several ways. Most obviously, they can be used to explain the reasons for the differences in overall evaluations. More importantly, though, these types of analyses can be used to suggest the types of changes in criterion weights that are required to change the relative evaluations of the candidates. For instance, Table 2-10 suggests that increases in the importance of RSI would tend to improve the 500's evaluation relative to that of the 58D, as would increases in the weight assigned to Other Operations and Support Cost or Airframe Performance. On the other hand, increases in the weights assigned to any other cost category would increase the 58D's preference over the 500, as would an increase in the weight assigned to Attainability. Changes in weights assigned to Operational Effectiveness or to most Technical Systems (other than airframe performance) would not change the relative evaluations of those two candidates.

2.2.4 Mixes of ASH Candidates - In addition to the thirteen ASH candidates discussed above, the Special Study Group is also interested in evaluating mixes of ASH candidates. These mixes use one helicopter to perform a high-capability mission role and a different one to perform a low-capability mission role and training and reserve roles. Two distinct models were used to evaluate different types of mixes. The first model evaluates four mixes of ASH candidates, assuming that the total number of helicopters to be purchased remains at 1472. The second model evaluates seven new mixes that vary the total quantity of helicopters as well as the mixtures.

2.2.4.1 Mixes involving 1472 helicopters - The first set of mixes evaluated assumed that 343 helicopters would be procured to serve for the high-capability role, 740 helicopters would be procured for the low-capability role, and 389 helicopters would be procured for the training and reserve roles. This gives a total procurement figure of

1472, which is the same size assumed for the homogeneous purchases of ASH candidates evaluated above.

The mixes to be evaluated included the following:

- 343 BTA plus 1129 OH-58C (B+C)
- 343 BTA plus 1129 OH-58D (B+D)
- 343 OH-64 plus 1129 OH-58C (64C)
- 343 OH-64 plus 1129 OH-58D (64D).

The model that evaluates these mixes uses the results of the model of homogeneous packages as a basis for simplification. Most importantly, the Military Worth of each mix is determined by aggregating the Military Worth evaluations of its components as determined by the original model. Table 2-11 shows the simplified method that is used to determine the Military Worth of the mixes. First, each mix is scored on its ability to perform the high role. This is simply the score of the candidate that fills the high role as determined by the model displayed on Table 2-7. Thus, mixes that have the BTA in the high role receive Military Worth scores of 76, and those that have the OH-64 in the high role receive scores of 60. A similar step determines the score of each mix in the low role; the score is that of the candidate filling the low role as determined by the model in Table 2-7. Thus, mixes that use the OH-58C receive scores of 24, and those that use the OH-58D receive scores of 36. (The analysts questioned whether the scores of the helicopters serving in the low role should be raised to reflect a lesser required capability. The users responded, however, that the scores of these particular candidates should not be raised.) Next, weights were assessed across the high and low roles. These weights, which are displayed in Table 2-11, are based on the assessment that the range of impacts of the candidates on fulfilling the high role is

1.1	- ASH		- MIL WORTH				
	FACTOR		WT	B+C	B+D	64C	64D
1)	MW HIGH	*(	55)	76	76	60	60
2)	MW LOW	*(	45)	24	36	24	36
	TOTAL			53	58	44	49

WEIGHTS BASED ON:

(1) HIGH ROLE IS MUCH MORE IMPORTANT

(2) MORE HELICOPTERS IN LOW ROLE (343 HIGH VERSUS 740 LOW)

Table 2-11

MILITARY WORTH ASSESSMENTS FOR MIXES OF 1472 HELICOPTERS about twice as important as the range of impacts on the low role. This assessment was then adjusted to account for the greater number of helicopters that will fulfill the low role. (The adjustment was made judgmentally in this evaluation but was formalized in the following one.)

Scores of the mixes on Force Structure Personnel Impact and RSI were also estimated based on the previous evaluation model. However, in the categories of Life Cycle Costs and Attainability, scores were assessed at all of the end-branches of the original model. The structures for these scores are shown in Figures 2-8 and 2-9.

The evaluations of the mixes can then be displayed on the same plot as Figure 2-11, which is done in Figure 2-13. Examination of this plot reveals that only one of the mixes is efficient: the BTA coupled with the 58C. This efficient mix offers about one-half of BTA's improvement over 58C at about one-half of the corresponding increase in "cost."

2.2.4.2 Mixes with different numbers of helicopters - Later discussions resulted in another set of mixes to be evaluated. Mixes in this set varied in the number and types of helicopters serving the high role and low role as follows:

Mix	High Role	Low Role
A	750 BTA	0
1	615 BTA	468 OH-58D+
2	490 BTA	593 OH-58D+
3	363 BTA	720 OH-58D+
4	490 BTA	260 OH-58D+
5	363 BTA	387 OH-58D+
6	270 OH-64	387 OH-58D+
7	264 OH-64-M	387 OH-58D+

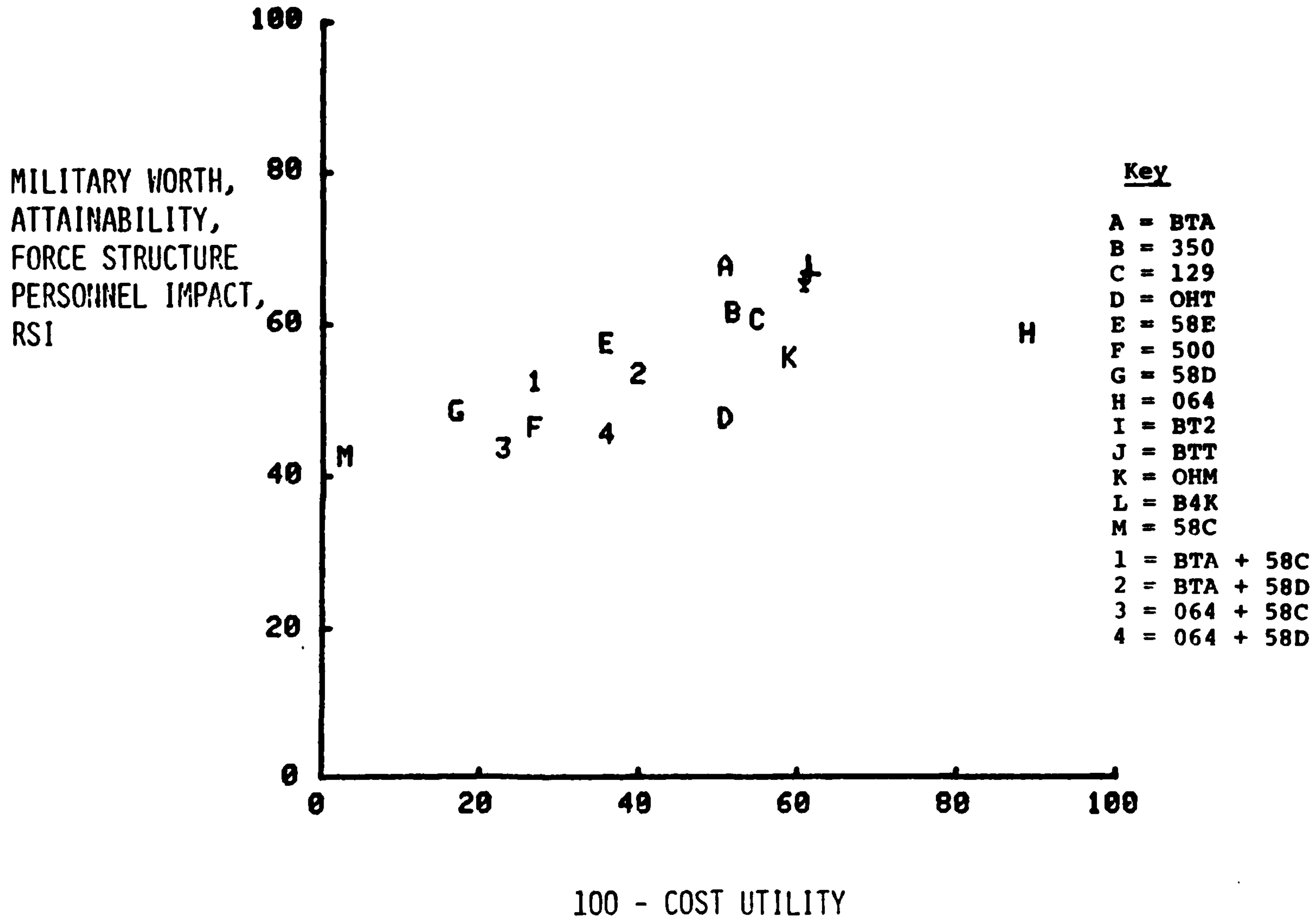


Figure 2-13

PLOT OF EVALUATIONS OF MIXES

Mix "A" is really not a combination of two ASH alternatives, but simply a reduced order of the BTA. Mixes 2 and 3 total 1083 helicopters and use various numbers of BTAs in the high role and OH-58D+s in the low role. (The OH-58D+ is an enhanced version of the OH-58D). Mixes 4 and 5 use fewer (750) of the same helicopters. Mixes 6 and 7 substitute versions of the OH-64 for the BTA and are targeted to cost the same (in APA dollars) as mix 5. Mix 6 uses the same OH-64 evaluated in Section 2.2.2, which has a nose-mounted sight, and mix 7 uses a modification of the OH-64 that has a mast-mounted sight.

Since quick evaluations were required for these mixes, a simplified model was used. The model considers only Military Worth and Cost. (Since Figures 2-11 and 2-12 are so similar to each other, it seemed certain that an analysis which used only Military Worth would produce a result very similar to that of an analysis that involved a more comprehensive measure of benefit). The scores for the mixes on Military Worth are based on those in the original model, but are adjusted for the number of units.

The scores of the mixes are shown in Table 2-12. The scores for the mixes containing the BTA in the high role begin with its assessed Military Worth of 76. This figure is then adjusted according to the number of units, using 750 as an estimate of the number required to serve the role completely. For instance, the mix with 615 BTA's receives a score of:

$$76 \times \frac{615}{750} = 62.$$

The mix that contains the ordinary OH-64 is scored by taking a proportion of the Military Worth score for the OH-64 determined in the original analysis, 60. The last mix is

			MIXES WITH A TOTAL OF 1083				MIXES WITH A TOTAL OF 750		MIXES "EQUAL" IN COST TO 363 BTA WITH 387 58D+	
		WT	750 BTA	615 BTA+ 468 58D	490 BTA+ 593 58D	363 BTA+ 720 58D	490 BTA+ 260 58D	363 BTA+ 387 58D	270 064+ 387 58D	264 064-M+ 387 58D
Military Worth	High	(67)	76	62	50	37	50	37	22	25
	Low	(33)	0	38	48	58	21	31	31	31
	Total		54	49	44	40	35	51	25	26
Cost	APA		$1.80B	$2.20B	$2.04B	$1.87B	$1.70B	$1.57B	$1.57	$1.58
	Total		$6.15B	$8.10B	$8.02B	$7.79B	$6.11B	$5.93B	$5.80B	$5.89B

Table 2-12

MILITARY WORTH SCORES AND COSTS OF
MIXES WITH DIFFERENT NUMBERS OF HELICOPTERS

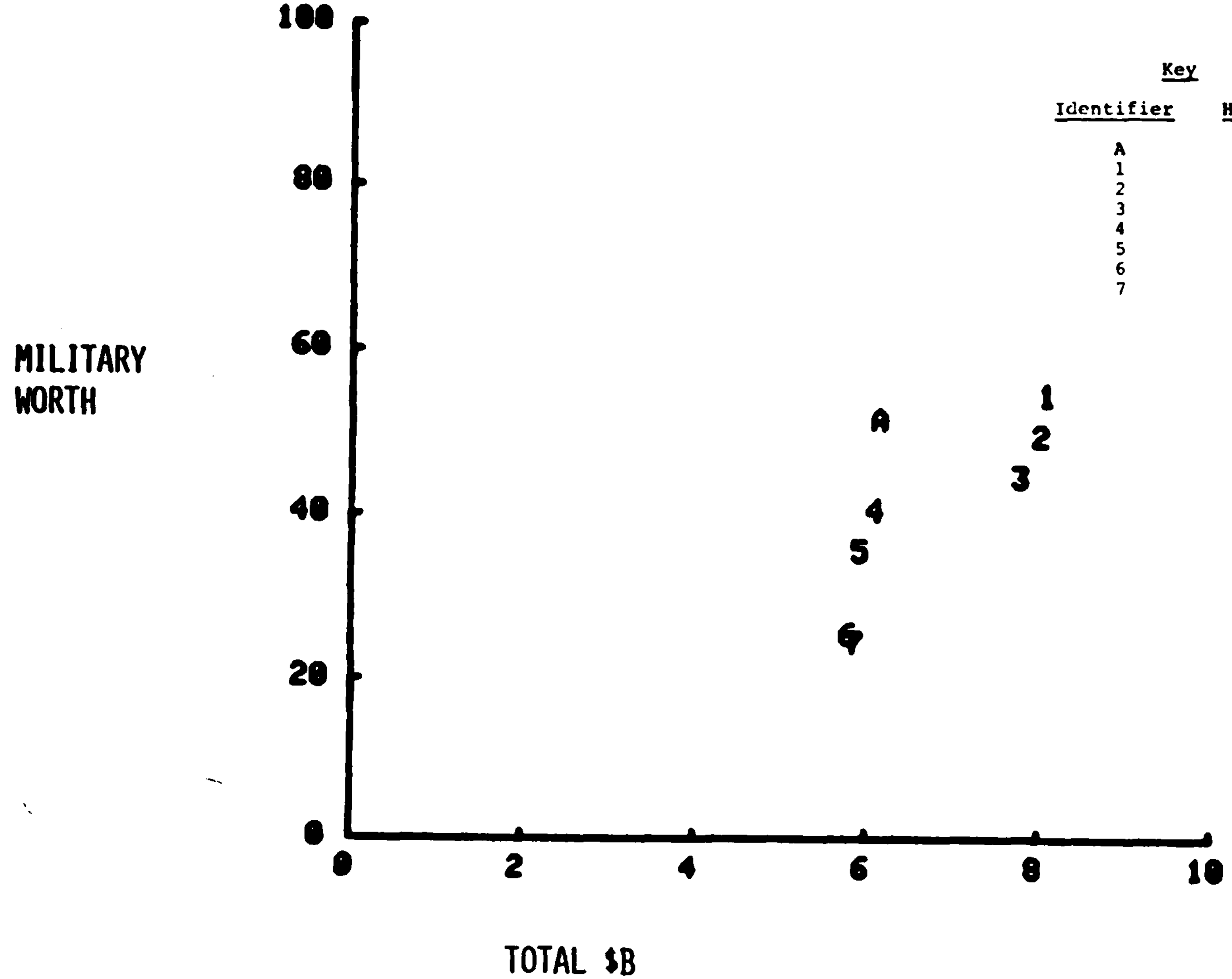
scored beginning with an assessment of the score for the OH-64-M. This score is estimated at 71, which is slightly above the score for the OHM; the OH-64-M is more survivable. These scores are then adjusted for the number of units involved.

Similar adjustments are made for scores in the low role. First, a score is assessed for the OH-58D+. This candidate was judged to be about as good as the 58E for the low role. So, the basic Military Worth score for the OH-58D+ was assessed at 58 (from Table 2-6). The score for each mix is calculated by adjusting this score by the number of units, assuming that 720 are required to fully perform the low role. For example, the mix that contains 468 OH-58D+s receives a score of:

$$58 \times \frac{468}{720} = 38.$$

The evaluations of the mixes on the basis of Military Worth are calculated, as before, by taking a weighted average of the scores. In this case, since the scores reflect the number of units to be procured, the proper weights are those that reflect the importance of the range of impacts of the candidates on the criteria. Specifically, the high role should receive a weight twice that of the low role.

Cost comparisons for these mixes are best performed on a total basis--rather than per unit--because different mixes involve different quantities. Estimates were made of the amount of each category of cost at different levels of procurement. Both the total cost and the APA costs of the mixes are given in Table 2-12. These evaluations can be plotted as shown in Figures 2-14 and 2-15. Figure 2-14 shows that the BTA is more efficient than any of the mixes on the basis of total cost. However, if all

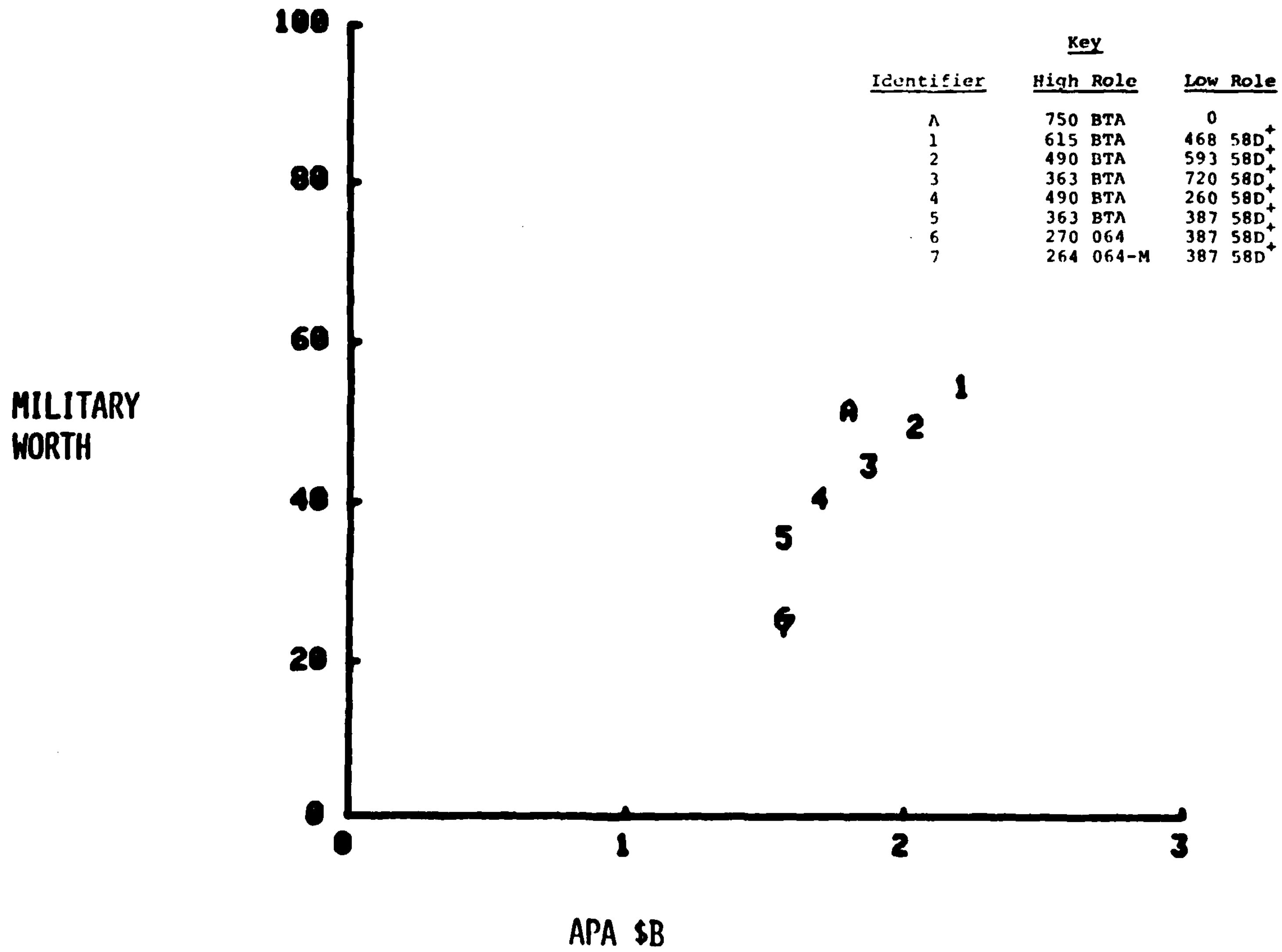


Key

Identifier	High Role	Low Role
A	750 BTA	0
1	615 BTA	468 58D+
2	490 BTA	593 58D+
3	363 BTA	720 58D+
4	490 BTA	260 58D+
5	363 BTA	387 58D+
6	270 064	387 58D+
7	264 064-M	387 58D+

Figure 2-14

MILITARY WORTH OF MIXES WITH VARYING
QUANTITIES VERSUS TOTAL COST



Key

Identifier	High Role	Low Role
A	750 BTA	0
1	615 BTA	468 58D+
2	490 BTA	593 58D+
3	363 BTA	720 58D+
4	490 BTA	260 58D+
5	363 BTA	387 58D+
6	270 064	387 58D+
7	264 064-M	387 58D+

Figure 2-15

MILITARY WORTH OF MIXES WITH
VARYING QUANTITIES VERSUS APA COST

costs other than APA (procurement) cost are ignored, then the mix of 363 BTA's and 387 OH-58D+'s is also efficient, as shown in Figure 2-15.

2.3 An Alternative Interpretation of the ASH Evaluation Model

Sections 2.1 and 2.2 explain the methodology used in constructing an evaluation model and describe details of the model built to evaluate ASH candidates. This section describes, in a series of charts, an alternative way of interpreting the model. This interpretation begins by taking the results of the COEA simulations (CARMONETTE and AVWAR) as an initial evaluation of the ASH candidates and then adjusts this evaluation to reflect items that were not included in the simulations.

The first adjustment considers individual differences among the 13 candidates that were not modelled in the simulation (such as the field artillery mission). The second adjustment reflects the equipment evaluations made by the technical community. The third adjustment factors in considerations of technical risk and training requirements. The fourth adjustment accounts for Attainability, Force Structure Personnel Impact, and RSI. The result of these adjustments is an evaluation of each candidate on all attributes of value except cost. This evaluation is the same one that is plotted against the utility for cost in Figure 2-13. These steps are displayed on the following charts.

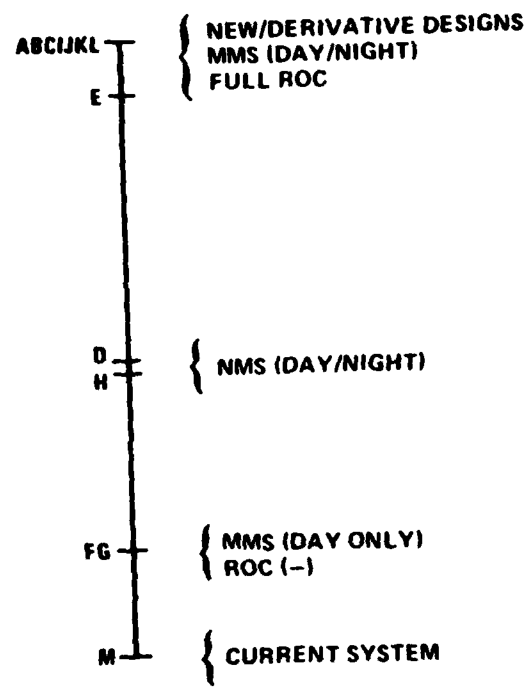
ASH Alternatives

A. New Dev 1 x ATE (BTA)
B. AS 350 (350)
C. A 129 (129)
D. OH-1 w/TADS (OHT)
E. OH-58E (58E)
F. Hughes 500D (500)
G. OH-58D (58D)
H. OH-64 (064)
I. New Dev 2 x ATE S x S (BT2)
J. New Dev 2 x ATE Tandem (BTT)
K. OH-1 w/MMS (OHM)
L. I with 4K/95 OEI (B4K)
M. OH-58C (58C)

COEA Simulations

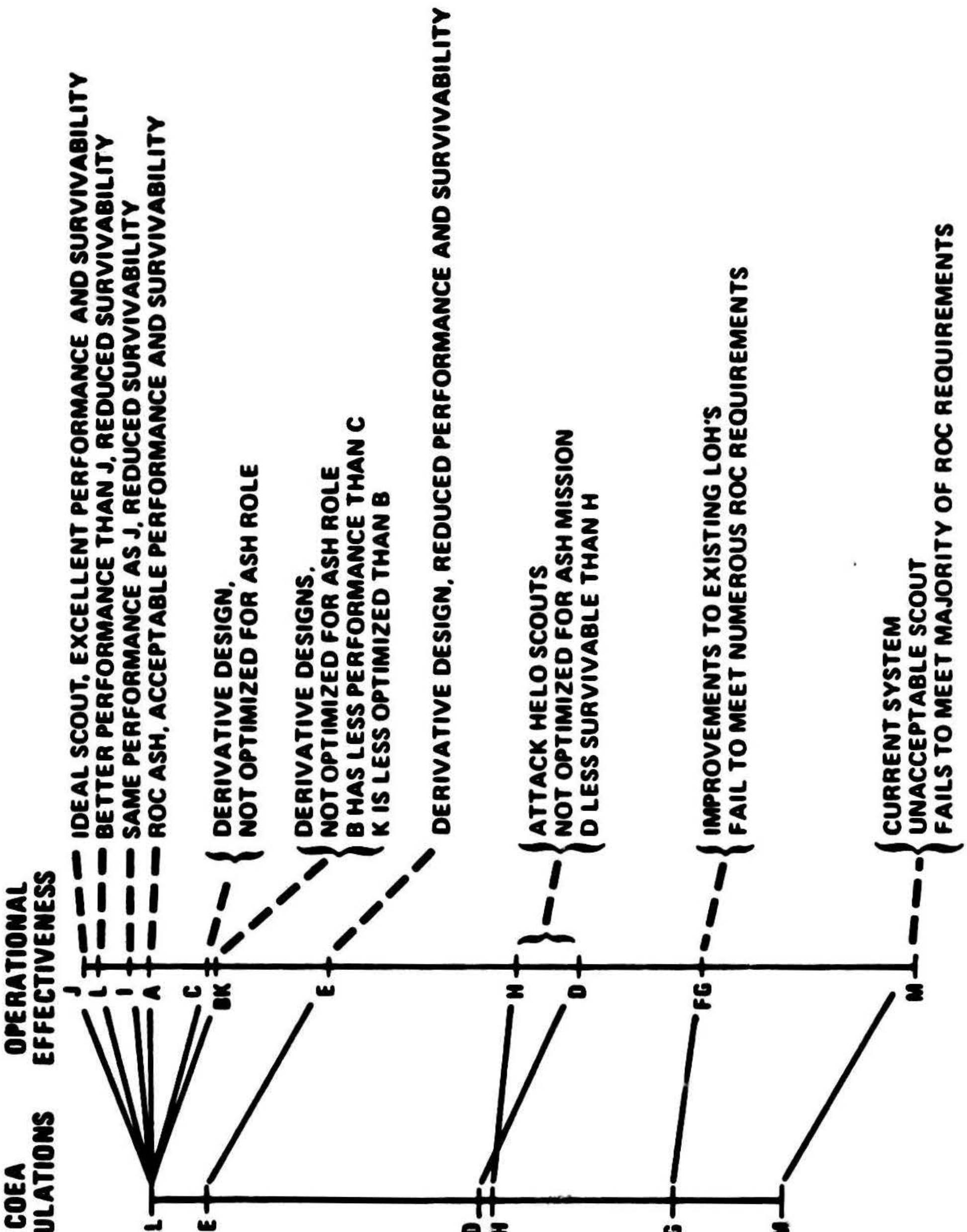
- **CARMONETTE (AHC SCOUT)**
  - *Force loss exchange ratio (FLER)*
    (Total red losses/total blue losses)
  - *Specific exchange ratio (SER)*
    (Red armor losses to helos/blue helo losses)
  - *Survivability ratio (SR)*
    (Blue helos at start/blue helos at finish)
- **AVWAR (CAV SCOUT)**
  - *Target detection ratio*
    (Number of targets in area at start/number of targets detected)
  - *Target recognition ratio*
    (Number of targets in area at start/number of targets recognized)
  - *FLER*
  - *SER*
  - *SR*

COEA SIMULATIONS



Operational Effectiveness

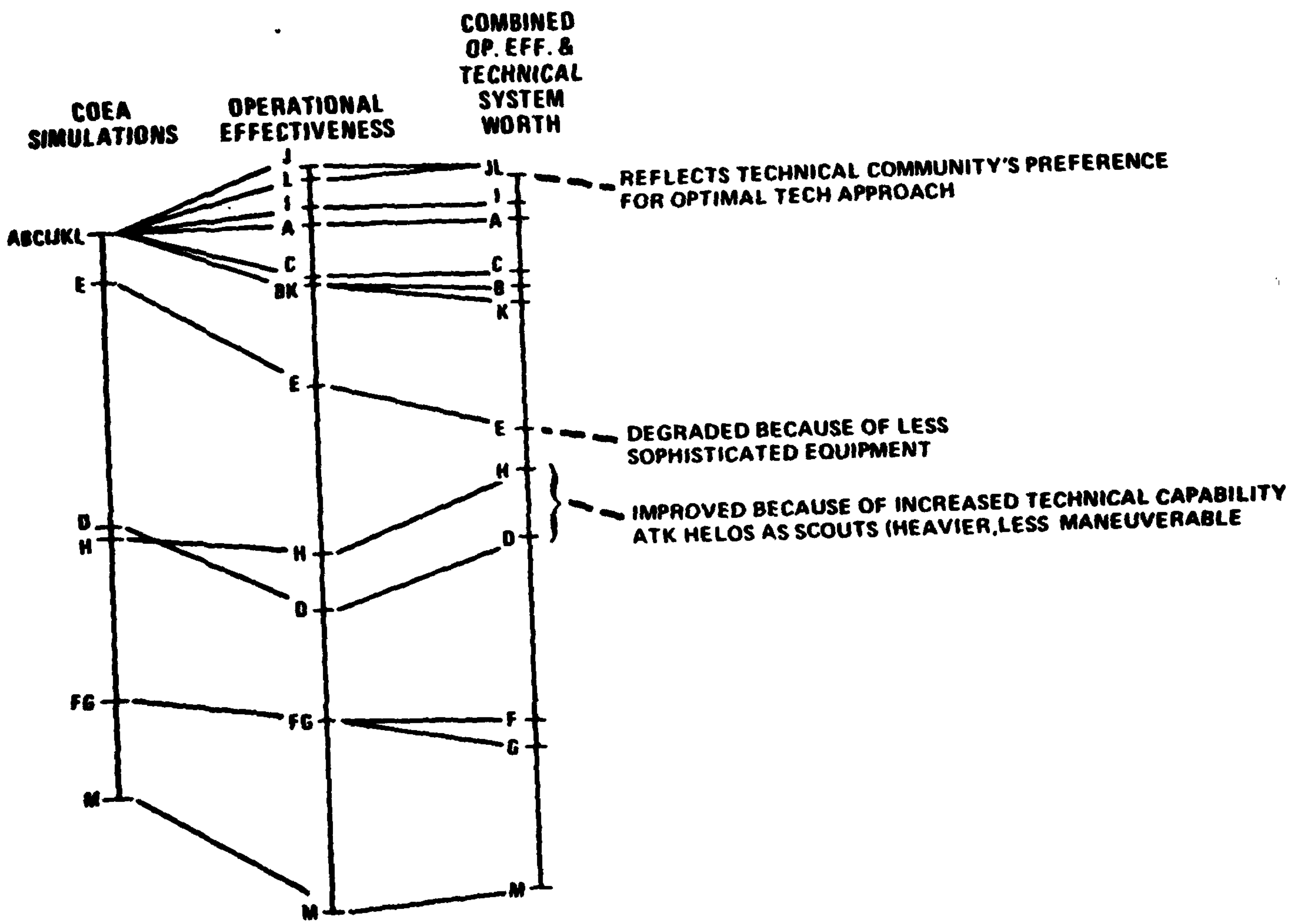
- **COEA SIMULATIONS**
- **MISSION AREA ANALYSIS**
    - *Considers*
        - **AIR CAV & FA SCOUT**
        - **AHC SCOUT**
    - *Includes adjustments for*
        - **TWIN ENGINES**
        - **SURVIVABILITY**
        - **SYSTEM CAPABILITIES**



COEA SIMULATIONS
OPERATIONAL EFFECTIVENESS
ABCIJKL
E
D
H
FG
M
J
L
I
A
C
BK
E
H
D
FG
M
IDEAL SCOUT, EXCELLENT PERFORMANCE AND SURVIVABILITY
BETTER PERFORMANCE THAN J, REDUCED SURVIVABILITY
SAME PERFORMANCE AS J, REDUCED SURVIVABILITY
ROC ASH, ACCEPTABLE PERFORMANCE AND SURVIVABILITY
DERIVATIVE DESIGN,
NOT OPTIMIZED FOR ASH ROLE
DERIVATIVE DESIGNS,
NOT OPTIMIZED FOR ASH ROLE
B HAS LESS PERFORMANCE THAN C
K IS LESS OPTIMIZED THAN B
DERIVATIVE DESIGN, REDUCED PERFORMANCE AND SURVIVABILITY
ATTACK HELO SCOUTS
NOT OPTIMIZED FOR ASH MISSION
D LESS SURVIVABLE THAN H
IMPROVEMENTS TO EXISTING LOH'S
FAIL TO MEET NUMEROUS ROC REQUIREMENTS
CURRENT SYSTEM
UNACCEPTABLE SCOUT
FAILS TO MEET MAJORITY OF ROC REQUIREMENTS

Combined Operational Effectiveness and Technical System Worth

- **OPERATIONAL EFFECTIVENESS**
- **TECHNICAL SYSTEM WORTH**
  - *MEQ Package*
  - *Airframe*
  - *System Integration*
- **TRADE OFFS**
  - *User's preference for light weight and maneuverability*
  - *Technical community's preference for equipment performance*


COEA SIMULATIONS
OPERATIONAL EFFECTIVENESS
COMBINED OP. EFF. & TECHNICAL SYSTEM WORTH
ABCIJKL
E
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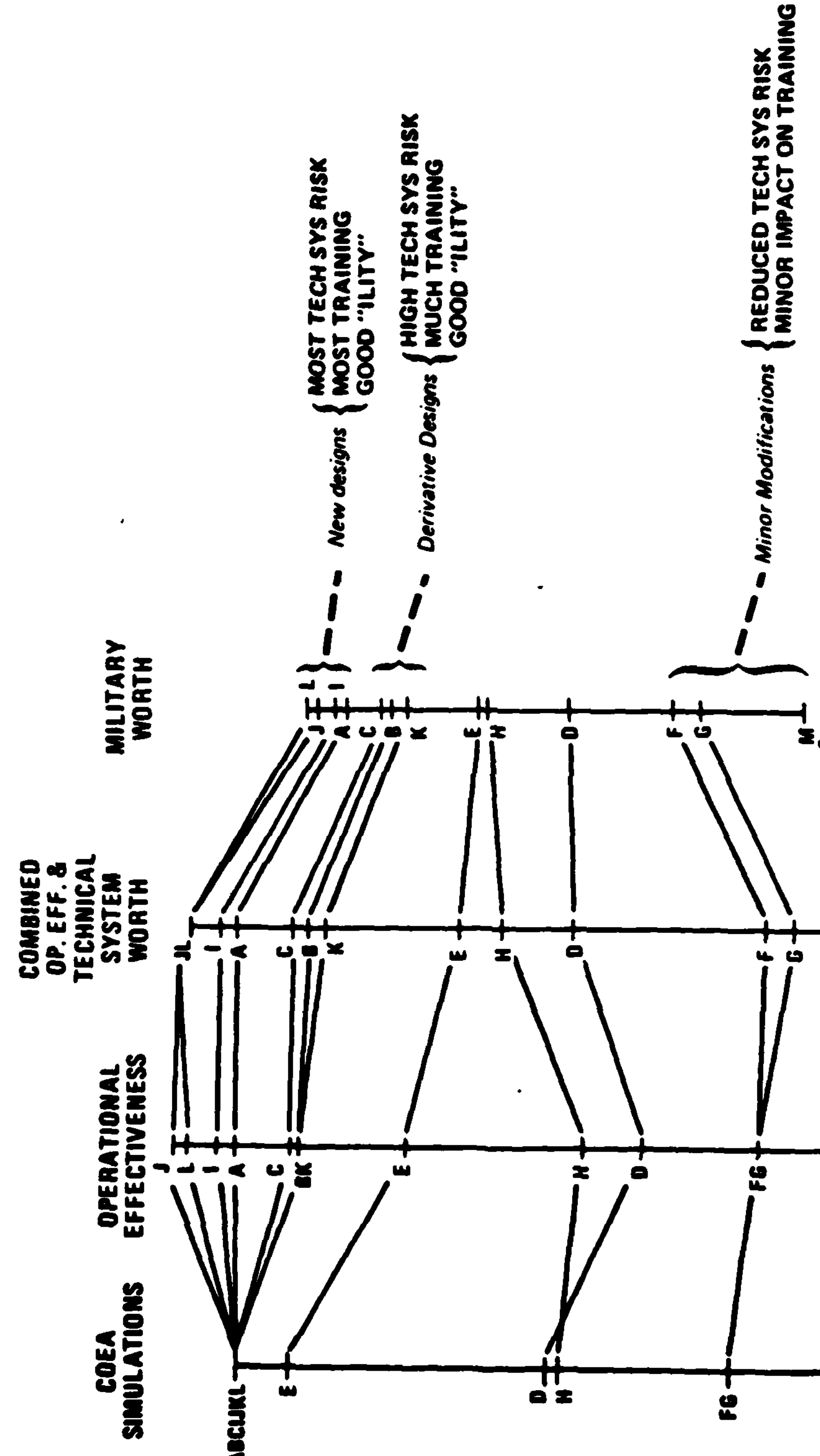
G
M
REFLECTS TECHNICAL COMMUNITY'S PREFERENCE FOR OPTIMAL TECH APPROACH
DEGRADED BECAUSE OF LESS SOPHISTICATED EQUIPMENT
IMPROVED BECAUSE OF INCREASED TECHNICAL CAPABILITY ATK HELOS AS SCOUTS (HEAVIER,LESS MANEUVERABLE

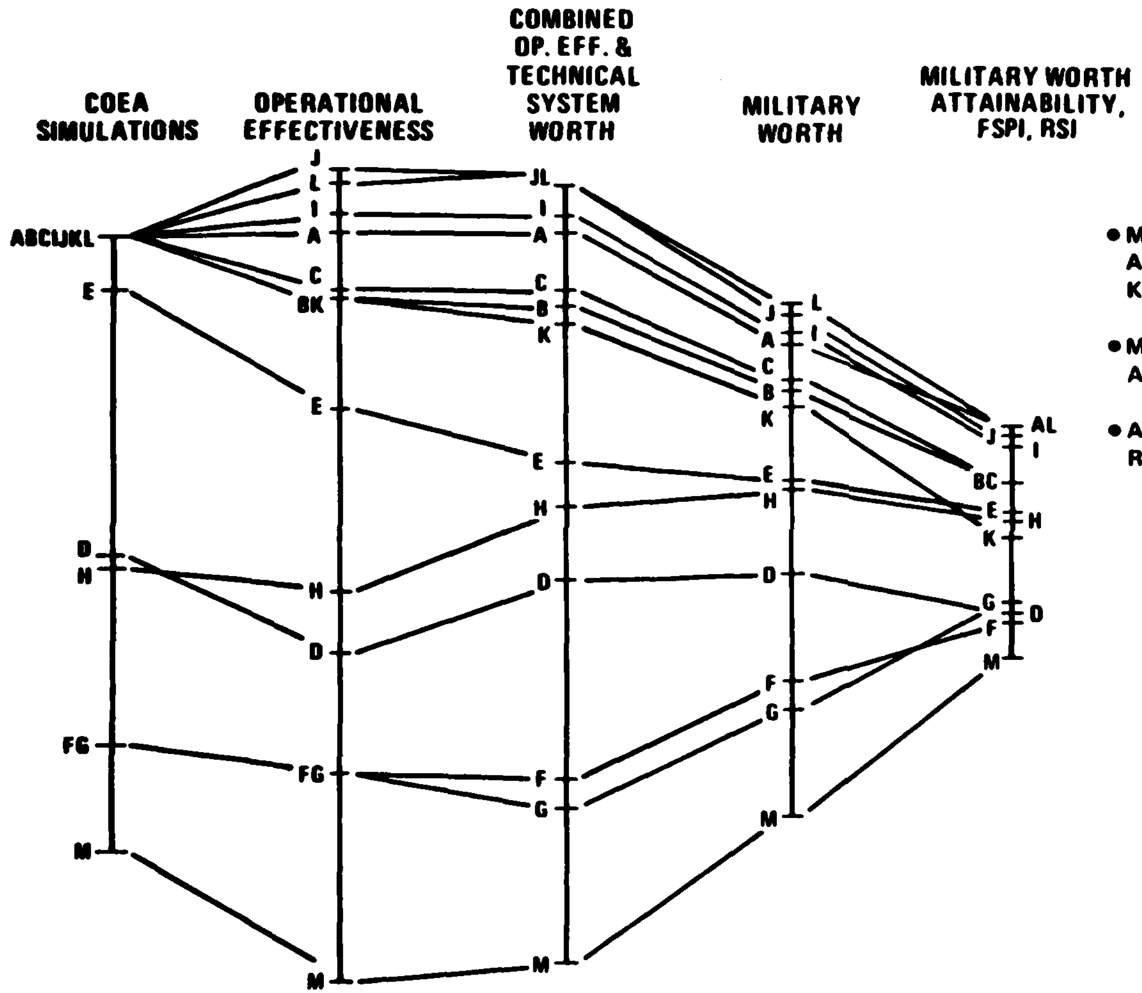
Military Worth

- **OPERATIONAL ACCEPTABILITY**
  - *Operational effectiveness*
  - *Availability*
  - *Training*
- **TECHNICAL SYSTEM WORTH**
- **SYSTEM RISKS**


COEA SIMULATIONS
OPERATIONAL EFFECTIVENESS
COMBINED OP. EFF. & TECHNICAL SYSTEM WORTH
MILITARY WORTH
ABCIJKL
E
D
H
FG
M
J
L
I
A
C
BK
JL
B
K
F
G
New designs
MOST TECH SYS RISK
MOST TRAINING
GOOD "ILITY"
Derivative Designs
HIGH TECH SYS RISK
MUCH TRAINING
GOOD "ILITY"
Minor Modifications
REDUCED TECH SYS RISK
MINOR IMPACT ON TRAINING

Military Worth, Attainability, FSPI, RSI

- **MILITARY WORTH**
- **ATTAINABILITY**
  - *Affordability*
  - *Schedule*
  - *Risks (cost and schedule)*
- **FORCE STRUCTURE PERSONNEL IMPACT**
- **RATIONALIZATION, STANDARDIZATION, INTEROPERABILITY**
  - *Political*
  - *Schedule*
  - *Mission*



- MAJOR CHANGES:
  A AND G IMPROVE THEIR RELATIVE POSITIONS.
  K DECREASES ITS RELATIVE POSITION
- MAJOR REASON FOR CHANGES IS ATTAINABILITY
- ATTAINABILITY IS ALSO THE MAJOR REASON THAT THE SCALE COMPRESSES

3.0 THE DESIGN MODEL

3.1 Introduction

In addition to the evaluation model described in Section 2, some effort was made to identify efficient ASH configurations using a Design Model. Such a model identifies important factors and assesses the cost/benefit trade-offs of improvements on each factor. For a variety of reasons, which are mentioned in Section 3.4, this model proved to be inappropriate for the task at hand and was abandoned in favor of the exclusive use of the evaluation model. Nevertheless, the Design Model has been included in this report for completeness and as an illustration of a type of analysis that could, under different circumstances, be useful.

In general, a Design Model serves the following purposes:

(1) it enumerates a set of design options;

(2) it identifies the efficient (most cost-beneficial) designs; and

(3) it evaluates the efficiency of any proposed design and suggests improvements.

While a Design Model is ideal for determining whether a proposed design can be improved, it is not especially useful for evaluating a specified set of designs.

3.2 The Design Methodology

The purpose of DDI's Design methodology is to assist in the identification of efficient designs. There are three steps to this analysis:

Step 1 The variables that can differ between designs, and the specific levels over which they vary, are identified.

Step 2 Three quantities are determined:

- the cost of an improvement on each variable,
- the benefit associated with each improvement within a variable, and
- the relative importance across variables.

Step 3 The cost/benefit trade-offs are examined with an eye towards discovering cheaper designs that yield the same benefit as any proposed design and better designs for the same cost as the proposed design.

Steps 1 and 2 require the judgment of experts and are used as input to DDI's DESIGN software, which carries out Step 3.

3.2.1 The model structure - The basic component of a Design Model is a variable. Variables represent choices that the designer can make. For instance, ASH could be designed to be capable of differing speeds or it could be designed with different navigation equipment. Each of these factors, e.g., speed and navigation equipment, is a variable that can distinguish one design from another. The first part of a design analysis is to identify a set of variables that influence the cost or effectiveness of a design.

Once the variables have been identified, it is necessary to specify the levels over which they vary. This is done by identifying a minimal level that must be achieved, a maximal level that is as high as one could reasonably expect, and intermediate levels that offer more moderate design options. For instance, with the design variable Speed it was known that even a minimal ASH candidate (OH-58C) is capable of 115 knots, while speeds in excess of 195 knots do not add any benefit. Levels of 145 and 160 knots were included to reflect the possibility of intermediate designs. Thus, Speed could vary over four levels: 115, 145, 160, and 195 knots.

Sometimes, when it is difficult for the experts to generate design variables, they are asked to systematically compare hypothetical minimal and maximal designs. The minimal design has those features that are absolutely necessary; the maximal design is "gold-plated," containing all of the characteristics that one would like it to have. This procedure helps to generate variables.

One major restriction on the Design methodology is that the variables must be independent of each other. In other words, it must be reasonable to speak of each level on the other variables. When this restriction is violated, the design software might suggest optimal designs that are impossible.

Once the set of design variables and the levels of each are known, designs can be generated by choosing one level on each variable. If the least desirable level on each variable is chosen, then the minimal design is described. If the most desirable levels are chosen, then the maximal design is described. Intermediate designs can be constructed by specifying high levels on some variables and low levels on others.

3.2.2 Assessing benefits and costs - Benefits are assessed for each variable independently. The lowest level is assigned a value of 0 and the highest a value of 100. Intermediate levels are assigned values reflecting the percent of the maximum attainable improvement that they provide. The relative importance of each variable in terms of its contribution to benefit is reflected by a weight associated with each variable. This weight reflects the benefit of going from the miminal to the maximal level on the variable. The most important variable is usually assigned a weight of 100. Then, the other variables are assigned weights that reflect their importance as measured against the maximum improvement on the most important variable. For instance, if navigation equipment is assigned a weight of 70 and TADS equipment a weight of 100, this would imply that an improvement from the lowest to the highest level on navigation equipment is worth 70% of the benefit derived from an improvement from the lowest to the highest level on TADS equipment. Later, these weights are normalized to add to 100. (This assessment of benefits is consistent with the "relative" method discussed in Section 2.1.)

Costs are also assessed for each level of each variable; in cases where actual costs of various levels are known, these figures are entered into the model. In other cases, the model can use incremental costs of moving from one level to another. As with the benefits, the model accommodates variables with independent costs. If cost dependencies exist among the variables, then the model is restructured to achieve independence.

3.2.3 Exercising the Design model - The procedure for calculating the total costs and total benefits of any particular design is to add them up, respectively. Thus, the total cost of a particular design is the sum of the costs associated with each level on each variable comprising it. The total benefit of a particular design is the sum of its weighted benefit scores.

If the set of all possible designs is plotted on a cost/benefit graph, the designs will tend to fall within the lens-shaped region depicted in Figure 3-1. (Note that the costs are rescaled to add to 100 for this display.) The solid upper line is called "the frontier." It indicates the designs which are efficient, i.e., those that produce the most benefit for any given cost. Often, a proposed design will fall somewhere below the frontier, such as at the point marked P. When this happens, it is possible to find a design that costs the same amount, but yields more benefit (marked B for better), as well as a design that yields as much benefit and costs less (marked C for cheaper). Careful consideration of these preferable designs represents the heart of the design evaluation.

The primary caution about the Design methodology is that variables must be constructed so that they are independent, and costs and benefits so that they are additive. An experienced analyst can usually construct a model to meet these requirements, at least as a first-order approximation to a more exact formulation.

3.3 Results

3.3.1 The structure of the model - Table 3-1 presents the design variables for ASH. Each of the eleven factors can vary over several levels, which constitute successively more costly alternatives.

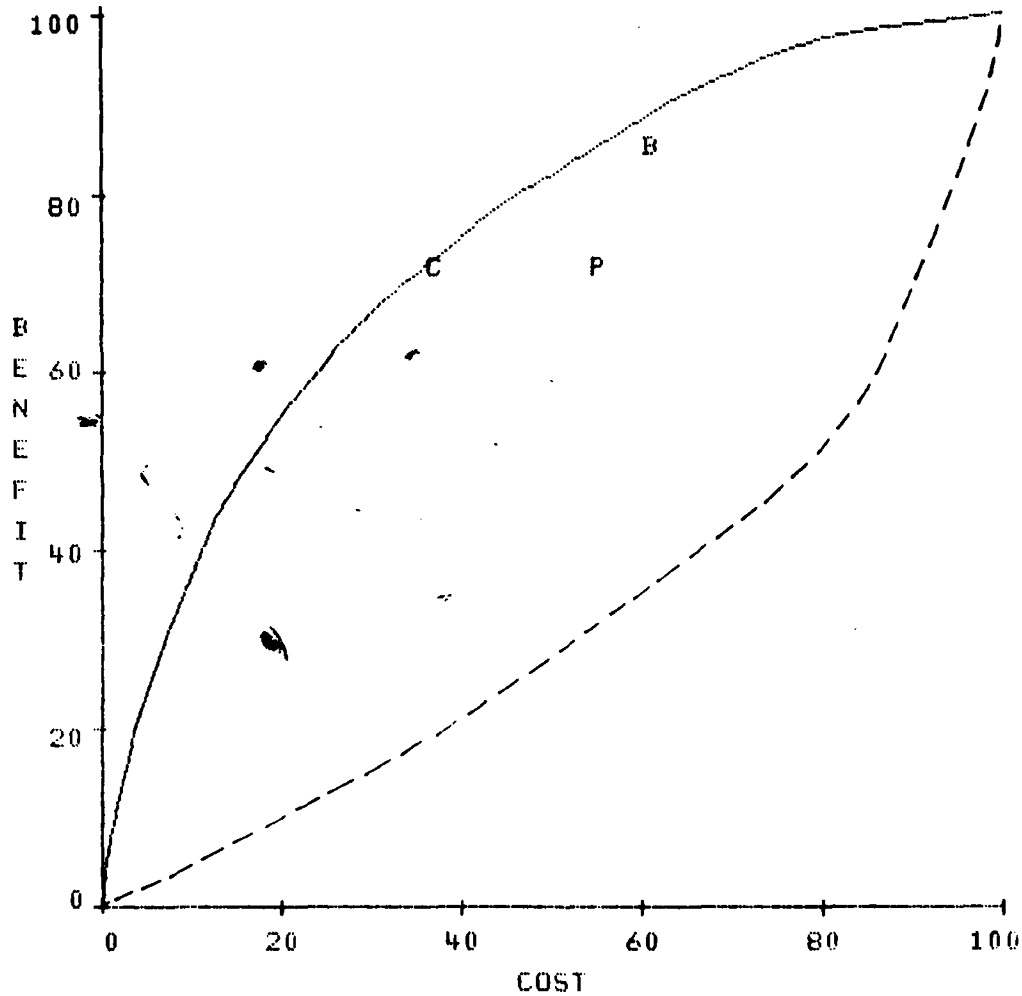


Figure 3-1
COST/BENEFIT TRADE-OFFS AND THE OPTIMAL FRONTIER

LEVEL / VARIABLE	Min Cost 1	2	3	4	5	6	Max Cost 7
1. Communications	2 IFM 1 UHF	2 IFM 1 UHF CPO HF	2 FM 1 UHF	2 IFM 1 UHF HF			
2. TADS	Verbal Hand-Off XM 21	Spot Tracker Day TV (MMS) LDRF	Spot Tracker ("E") FLIR/TV LDRF	FLIR/TV Video Record DMD	MMS (AH64 TADS)	MMS (FLIR, TV, LDRF, LST) DVO, DMD, Video	
3. Mission Equipment Growth	No Growth Capability	140 Pounds (Black Boxes)	440 Pounds (Black Boxes + 300 lb storage)	740 Pounds (Black Boxes + 600 lb storage)	1000 Pounds (Arms, Auto Our, + Equip.)		
4. ASE	IR Suppress Flat Canopy IR Paint APR 39 (V1)	APR 39 (V1) LWR, CPO (IR, Laser Jam; XM130)	Level 1 + APR 39 (V1,V2), IR Jammer	Level 1 + APR 39 (V1,V2), LWR	Level 4 + CPO/LWR, APR 39 (V2), Obs Stk Tol	Level 5 + Flat Plate	Level 2 + Level 6 + Wire Detector
5. Passive Protection	7.62	7.62/100 23 HE (Tail)	7.62/100 (Crew) 12.7/200 (A/F) 23 HE, 23 FB	12.7/800 23 HE	12.7/800 23 HE, 23 FB	12.7/200 23 HE, 23 FB	14.5/800 23 HE, 23 FB
6. One Engine Inoperable	Auto Rot. Single Fixed	SLF @ 4K/95 Twin Fixed	4K/95 HIGE Twin Rubber	Auto Rot Single Rubber	4K/95 HOGE Twin Rubber	2K/70 HIGE Twin Fixed	2K/70 HIGE Twin Rubber
7. Crash-worthiness	CW Fuel	CW Fuel Engr. Abs. Seat 8" Stroke	CW Fuel Engr. Abs Fuselage	Level 2 + Hi Mass Item Ret.	Level 4 + Engr. Abs Landing Gear	Level 5 + 90°, M.I. Ret Non Inj Environ	Level 6 + Hi M.I. Ret. 12" Stroke
8. Speed	115 Knots	145 Knots	160 Knots	195 Knots			
9. VROC @ 4K/95	HOGE @ IRP	500 FPM @ IRP	500 FPM @ 95 IRP	1500 FPM @ 95 IRP			
10. Transmission (VROC @ 2K/70)	500 FPM @ IRP	2000 FPM @ IRP	2000 FPM @ IRP	4000 FPM @ IRP			
11. Navigation	Nothing	ADF Mag. Compass	ADF Mag. Compass VOR/ILS	Level 3 + NVG, Doppler	CPO/GPS CPO/PMD Doppler, TBS, PNVS, AHRS	Doppler/DRS TBS, PMD, PNVS, AHRS, Hover Hold	

Table 3-1

THE ASH DESIGN VARIABLES

Table 3-2 presents the costs and benefit scores for the alternatives displayed in Table 3-1. Some of the cost estimates are absolute costs and others are relative costs. The benefit scores represent the percent of the total benefit within a variable that is obtained by a particular improvement above the minimal or least beneficial level. As such, the benefit scores do not yet reflect the relative importance of each variable.

One thing to notice about the ASH design variables is that increases in cost do not always correspond to increases in benefit. Four of the design variables--Communication Equipment, ASE, Passive Protection, and OEI--show this tendency. This feature results from an effort to provide levels that correspond to concrete options embodied in the set of available ASH alternatives. Undoubtedly, it is difficult to ascertain how much of the total cost of any alternative is attributable to each factor, and this leads to some unmatched orderings of cost and benefit. Nevertheless, insofar as these unmatched orderings are accurate, certain design options, e.g., Level 3 of Communications Equipment, are clearly undesirable.

Table 3-3 lists the weights assigned to the variables. These weights reflect the relative benefit obtained by improving a variable from its least beneficial level up to its most beneficial level. In addition, the weights reflect the importance of one factor in relation to the others. The relative benefit of any particular level of any variable is obtained by multiplying the benefit score in Table 3-2 by the appropriate weight in Table 3-3, then dividing by 100.

3.3.2 <u>The efficient designs</u> - The purpose of a design analysis is to discover the designs that are efficient, which means the designs that are most beneficial for a given

Variable	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
1 COMMUNICATION EQUIPMENT	$44.4K 60	$45.9K 80	$48.9K 0	$89K 100			
2 TADS	$1K 0	$250K 50	$300K 60	$400K 85	$500K 90	$550K 100	
3 MEQ GROWTH	$0K 0	$24K 15	$77K 45	$135K 75	$175K 100		
4 ASE	$11.2K 0	$29.1K 50	$31.1K 30	$33K 40	$34.8K 70	$38.3K 80	$163K 100
5 PASSIVE PROTECTION	$18.9K 0	$34.3K 25	$77.35K 70	$79.1K 50	$109K 60	$119K 85	$321K 100
6 OEI	$0K 0	$500K 75	$5M 93	$10M 10	$10M 100	$13M 85	$15M 90
7 CRASH-WORTHINESS	$0K 0	$30K 25	$60K 40	$90K 45	$120K 80	$150K 90	$180K 100
8 SPEED	$0K 0	$200K 80	$400K 90	$600K 100			
9 VROC @4K/95	$0K 0	$100K 50	$200K 85	$300K 100			
10 TRANSMISSION RATING	$0K 0	$100K 75	$200K 85	$300K 100			
11 NAVIGATION EQUIPMENT	$0K 0	$15K 10	$21K 20	$52K 60	$310K 90	$357K 100	

Table 3-2

COSTS AND BENEFITS ASSESSED FOR THE ASH DESIGN VARIABLES

	Variable	Weight
(1)	Communications	6.3%
(2)	TADS	15.7%
(3)	Mission Equipment Growth	3.1%
(4)	ASE	7.9%
(5)	Passive Protection	11.8%
(6)	One Engine Inoperable	11.8%
(7)	Crash-Worthiness	9.4%
(8)	Speed	6.3%
(9)	VROC @ 4K/95°	11.8%
(10)	Transmission Rating	4.7%
(11)	Navigation Equipment	11.0%
		99.8%

Note: The sum does not equal 100% due to round off errors.

Table 3-3

THE WEIGHTS FOR THE ASH DESIGN VARIABLES cost and least costly for a given amount of benefit. These designs form a "frontier" on a cost/benefit graph with the inefficient designs falling below this frontier. The efficient "frontier" of ASH designs, based on the assessments of costs and benefits in Table 3-2, is depicted in Figure 3-2.

The most striking characteristic of ASH's efficient "frontier" is that it rises very rapidly until about 20% of the total cost has been spent. Then it rises very slowly. In addition, at 20% of the cost, almost 100% of the relative benefit has been obtained. In other words, certain rather costly improvements provide very little additional benefit.

Upon examining the design that corresponds to the kink of Figure 3-2, the picture becomes clearer. A design with the most beneficial level on all variables (except OEI and with Level 2 on OEI) provides 97% of the relative benefit at 19% of the cost. This means that only the Twin Engine Fixed Rotor with SLF @ 4K/95° is cost-beneficial. All other engine designs are far too expensive to be justified (see Table 3-2). Moreover, improvements on design factors other than OEI should be considered before spending the money to improve OEI beyond Level 2. (This conclusion is based, however, on the estimated costs used in the model. As explained in Section 3.4, these cost estimates have little validity and are of illustrative value only.)

3.3.3 The proposed designs - Table 3-4 presents the thirteen proposed ASH designs and the levels they assume on each design variable. Figure 3-3 depicts the cost/benefit trade-offs for each of these alternative designs. These designs fall into two groups: one group that costs less than 20% of the total cost and follows the optimization curve

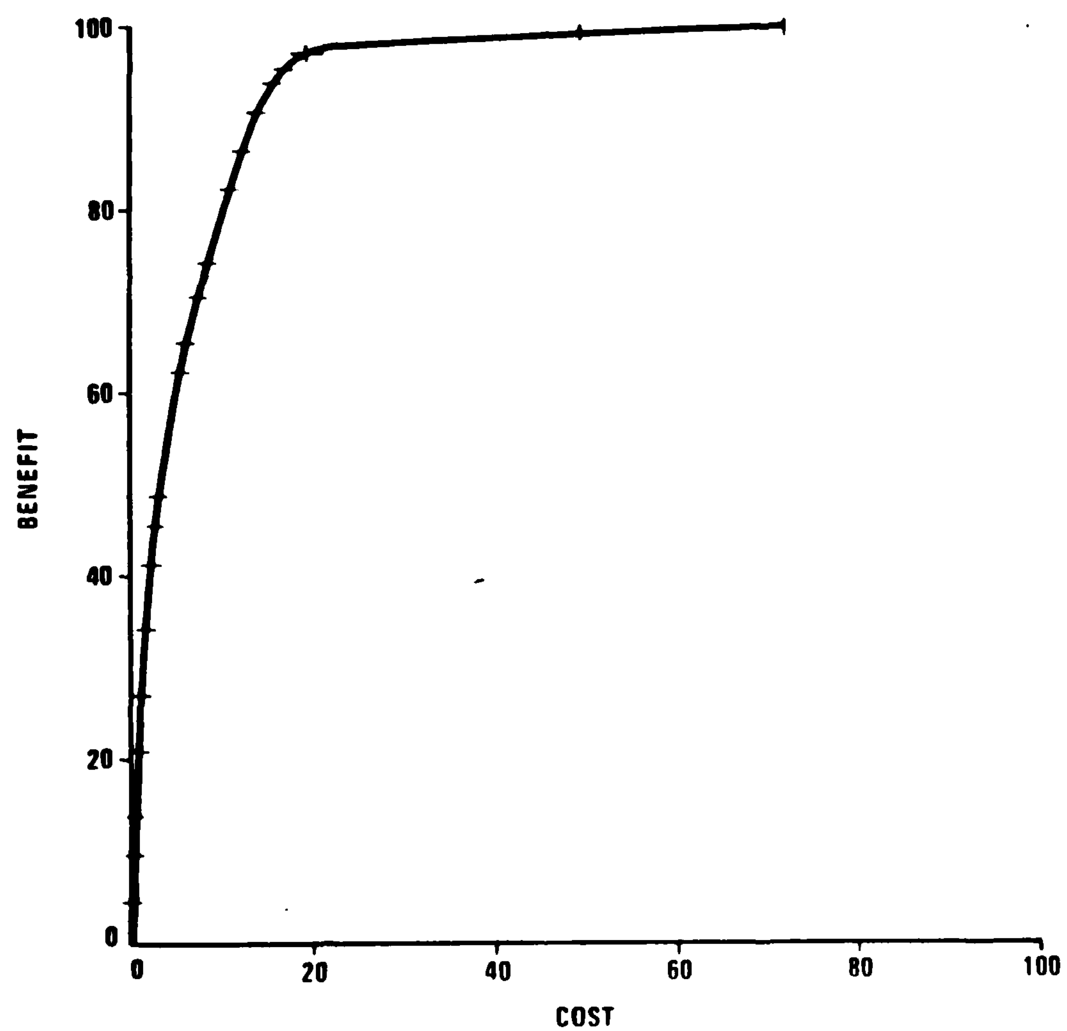


Figure 3-2

THE EFFICIENT "FRONTIER" OF ASH DESIGNS

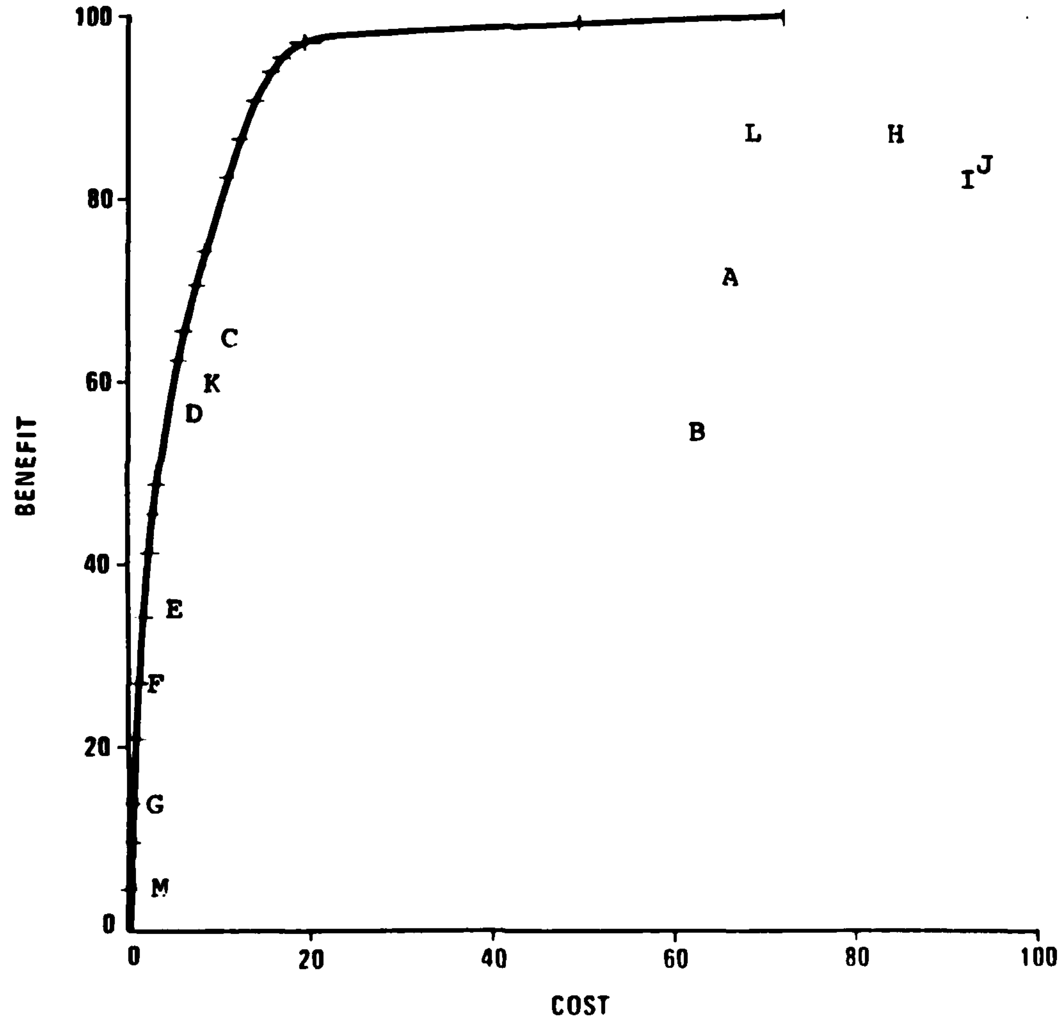


Figure 3-3

COST/BENEFIT TRADE-OFFS FOR THE 13 ASH CANDIDATES

	ASH Alternative	1 Comms	2 TADS	3 MEQ Growth	4 ASE	5 Passive Protection	6 OEI	7 Crash-Worthiness	8 Speed	9 VROC @ 4K/95	10 Trans Rating	11 NAV
A	NEW SINGLE ATE	2	4	4	5	4	4	7	3	3	2	5
I	NEW TWIN ATE S x S	2	4	4	5	4	7	7	3	3	2	5
J	NEW TWIN ATE TANDEM	2	4	4	5	5	7	7	3	3	2	5
B	AS-350	2	4	1	5	1	4	7	2	2	1	5
C	A-129	2	4	1	5	1	2	6	2	2	2	5
K	OH-1 MMS	2	4	2	5	4	1	4	3	2	2	5
D	OH-1 TADS	2	5	2	5	4	1	2	2	2	2	5
E	OH-58E	1	2	1	1	2	1	1	2	2	1	5
F	500MX	1	2	1	1	1	1	3	2	1	1	4
G	OH-58D	1	3	1	1	1	1	1	1	1	1	2
M	OH-58C	1	1	1	1	1	1	1	1	1	1	3
H	OH-64	2	5	5	7	5	6	5	3	4	3	6
L	NEW TWIN ATE S x S POWER FOR OEI	2	4	4	5	4	5	7	4	4	4	6

Table 3-4

DESIGNS OF ASH CANDIDATES

rather closely and another group that costs well over 20% of the cost and falls short of the optimization curve. (Again, these conclusions are based on invalid cost data.)

The reasons for the two groups becomes apparent when Table 3-4 is re-examined. The first group is composed of designs that have either Level 1 or Level 2 of OEI, i.e., a single or twin engine with fixed rotor, while the second group uses the more expensive engine designs. This indicates that OEI is the driving force in the present analysis.

The design analysis does not determine a single "best" design. The Design methodology can, however, suggest how pre-specified options might be improved. For example, in Design C, a decrease in the capability of the navigation equipment (from Level 5 to Level 4) would permit improvements in:

(a) Communications (Levels 2-4);

(b) Mission Equipment Growth (Levels 1-3);

(c) ASE (Levels 5-6);

(d) Passive Protection (Levels 1-6);

(e) Crash-Worthiness (Levels 6-7); and

(f) VROC (Levels 2-4).

These changes would improve the overall benefit of Design C without increasing its cost. A similar analysis for Design L suggests that Design L's cost is so great that it would be only marginally more expensive to purchase the most beneficial level on all factors. This would involve improvements in:

(a) Communications (Levels 2-4);

(b) TADS (Levels 4-6);

(c) Mission Equipment Growth (Levels 4-5);

(d) ASE (Levels 5-7); and

(e) Passive Protection (Levels 4-7).

These suggestions for improved designs demonstrate the type of analysis for which Design models are best suited.

3.4 Comments on the Design Model

The Design model of ASH alternatives described above is an initial attempt to structure this problem. As such, the model suffers from the typical problems of initial models which are usually worked out in subsequent refinements. These include problems in both the model's structure and inputs. The results of the model, therefore, are only illustrative; they are not valid and serve no other purpose. The discussion below details each of these problems and explains the reasons why the model was not refined.

The major problem with the model's structure is the interaction among the OEI variable, which addresses the type of engine in the helicopter, and other variables. For example, the type of engine determines the maximum permissible weight which determines the amount of equipment that can be added. A possible way to correct this problem would be to model the remaining variables within the constraint of each major type of engine and then to tie the separate models together in an overall model. This solution is compatible with the modeling approach but was not undertaken for reasons explained below.

The inputs to the model were assessed in a very short period of time using the best available sources. There were problems with inputs because the time period was so short and because the best sources of data were not always available. The latter problem was especially true for the estimates of costs. Costs often had to be assessed by technical experts who had little confidence in their ability to estimate cost. In addition, some cost figures were provided by DDI analysts in order to get the model up and running. These figures were intended to be used for demonstration purposes only and to be revised by cost experts. Such problems with inputs are common to all modeling efforts and would have been solved in the normal course of refining the model. However, since the model was not refined, the problem remains.

During the process of refining the Design model, we discovered that the real interest was in evaluating the 13 identified ASH candidates rather than in devising the most efficient ASH design. This is the main reason for halting work on the Design model and for concentrating the remaining effort on the Evaluation model.

4.0 CONCLUSION

In the preceding chapters, the nature of the decision-analytic modeling effort performed by DDI for the ASH SSG has been described. While the DDI modeling effort has not recommended a single ASH candidate over all others, it has allowed the SSG to more fully understand trade-offs of the competing decision-related variables with one another. For a chosen set of importance weights allocated across these variables, it is possible to state which candidate is of the most worth to the Army and which candidates are most efficient. All numerical assessments have been supported through written rationale, and it has been possible to vary any score or weight that may be in question and to determine the impact of such variations on the result.